Early and Late Spanish-English Bilingual Adults' Perception of American English Vowels

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ABSTRACT

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Increasing numbers of Hispanic immigrants are entering the US (US Census Bureau, 2011) and are learning American English (AE) as a second language (L2). Many may experience difficulty in understanding AE. Accurate perception of AE vowels is important because vowels carry a large part of the speech signal (Kewley-Port, Burkle, & Lee, 2007). The relationship between native language and L2 vowel inventories causes some vowels to be more difficult to perceive accurately than others (Best & Tyler, 2007). The present study examined the patterns with which early and late Spanish-English bilingual adults assimilate AE vowels to their native vowel inventory and the accuracy with which they discriminate and identify the vowels. Early bilingual listeners demonstrated similar perceptual assimilation patterns to late bilingual listeners, but judged AE vowels as less Spanish sounding than did late learners. Additionally, discrimination and identification accuracy of L2 vowels improved with early age of L2 acquisition. However, early bilingual listeners' vowel perception was not native-like. Certain AE vowels (/ʌ/, /ɑ/ and /æ/) were difficult to discriminate and identify. Perceptual assimilation patterns predicted categorial discrimination accuracy, an outcome posited by the Perceptual Assimilation Model-L2 (Best & Tyler, 1997).

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Chapter 1. Introduction

Increasing numbers of Hispanic immigrants are entering the US (US Census Bureau, 2011) and learning American English (AE) as a second language (L2). Many may experience difficulty in understanding AE. Their reduced understanding of AE may negatively impact their interactions with individuals in their social, academic, and professional communities. Accurate perception of AE vowels, most effectively acquired in early childhood (Flege & MacKay, 2004; Flege, MacKay, & Meador, 1999; Mack, 1989; Polka & Werker, 1994), is important because vowels carry a large part of the speech signal (Kewley-Port, Burkle, & Lee, 2007).

The present study examined the patterns with which early and late Spanish-English bilingual adults assimilate AE vowels to their native vowel inventory and the accuracy with which they discriminate and identify the vowels. The following section summarizes the existing research relevant to the question of the effects of age of English acquisition on Spanish-English bilinguals' perception of AE vowels. It begins with an overview of cross-language speech perception and production models and is followed by a comparison of Spanish and English vowel inventories. Lastly, the factors contributing to the accuracy of L2 vowel perception by late Spanish-English bilingual listeners are reviewed.

1.1 Models of Cross-Language Speech Perception and Production

Second language learners often have difficulties perceiving and producing L2 speech sounds that do not exist in their native language. The relationship between native language and L2 speech sound inventories causes some speech sounds to be more difficult to perceive accurately than others (Best & Tyler, 2007). The perceptual

interaction between native language and L2 speech sounds is explained through models of cross-language speech perception.

Among the most influential models of cross-language and L2 speech perception and production are the Perceptual Assimilation Model (PAM) for naïve listeners (Best, 1995), the Perceptual Assimilation Model for L2 learners (PAM-L2) (Best & Tyler, 2007), the Second Language Linguistic Perception Model (L2LP) (Escudero, 2005), and the Speech Learning Model (SLM) (Flege, 1995). The PAM (Best, 1995) makes predictions about how naïve listeners will assimilate non-native speech sounds to the phonological categories of their native language. According to the PAM, accuracy in discrimination depends on how non-native speech sounds are assimilated into the native language speech sound inventory. For example, in the two-category assimilation type pattern, each non-native speech sound is assimilated to a different native category and is expected to yield excellent discrimination accuracy. When both non-native speech sounds are assimilated to the same native category, but one speech sound is considered a better exemplar than the other in the category-goodness assimilation type pattern, moderate to very good discrimination accuracy is predicted. In the uncategorized versus categorized assimilation type pattern, one non-native speech sound assimilates to a native category and the other falls in phonetic space that is not within particular native categories yielding very good discrimination accuracy. In the both uncategorizable assimilation type pattern, both non-native speech sounds are perceived as within native phonetic space, but not within any particular native category and is predicted to have very good to poor discrimination accuracy. Lastly, in the single-category assimilation type pattern, both

native speech sounds are assimilated to the same native category, but both are equally acceptable exemplars of the category and poor discrimination accuracy is predicted.

The PAM-L2 (Best & Tyler, 2007) is an extension of the PAM and makes predictions about perceptual patterns in L2 learning. This model posits that when two L2 speech sounds are assimilated to the same native category and one of them is considered to be a better exemplar than the other, a new category is unlikely to be formed for the deviant L2 speech sound. However, with continued L2 exposure, the deviant speech sound may be learned as a variant of the native language speech sound. A new L2 category is gradually formed as the language learner becomes aware of the relevant contrasts between speech sounds.

Consistent with the PAM (Best, 1995), the Second Language Linguistic Perception Model (L2LP) (Escudero, 2005) makes predictions about perceptual patterns based on a comparison of L2 and native categories. However, the L2LP model proposes various learning scenarios. For instance, in the PAM's two-category assimilation type pattern each L2 speech sound within a contrast is perceived as a separate native category. The L2LP model proposes that in this "similar scenario" L2 listeners will shift native categories so that new boundaries are created to reflect the phonetic properties of the L2 speech sounds. Furthermore, in the PAM's single category assimilation type pattern, L2 speech sounds are perceived as a single native speech sound. The L2P2 model proposes that in this "new scenario" L2 listeners will create a new category or split an existing native category in order to accommodate the new speech sounds. The L2LP model proposes that a category boundary shift that occurs in the "similar scenario" is easier to achieve than the category creation or split that occurs in the "new scenario".

The models discussed above investigate perception in L2 learning, whereas the Speech Learning Model (SLM) (Flege, 1995) investigates perception and production by L2 learners. According to the SLM the similarity of L2 speech sounds to native language categories is important for explaining the difficulties that arise in L2 speech perception and production. The greater the perceptual difference between native language and L2 speech sounds, the more accurately L2 phonetic differences will be identified. The SLM posits that phonetic categories in the native language and L2 interact through the processes of category assimilation and dissimilation. Through category assimilation, native language and L2 categories merge and reflect the phonetic properties of native language and L2 speech sounds. Through category dissimilation, on the other hand, native language and L2 categories that are close in acoustic vowel space move away from one another to maintain the phonetic contrast between native and L2 speech sounds.

1.2 AE and Spanish Vowels

Differences in the native language and L2 vowel inventories may render some L2 vowels more difficult to perceive than others (Best & Tyler, 2007). The AE inventory of 11 vowels (/i/, /ɪ/, /u/, /ʊ/, /e/, /o/, /ɛ/, /ʌ/, /ɔ/, /æ/, /ɑ/) is larger than the Spanish inventory of five vowels: /i/, /u/, /e/, /o/, and /a/. AE has a corresponding tense and lax vowel (/i/-/ɪ/, /u/- /ʊ/) for each of the high front (/i/) and high back (/u/) vowels of Spanish. AE has five mid vowels /e/, /o/, /ɛ/, /ʌ/, and /ɔ/, whereas Spanish has two mid vowels /e/ and /o/. Additionally, AE has two low vowels (/æ /, /ɑ/) and Spanish has only one low vowel (/a/). In terms of acoustics, AE vowels /i/, /e/, /o/, and /u/ have higher second formant frequencies (F2s) than Spanish vowels /i/, /e/, /o/, /u/ respectively, indicating a more fronted lingual position in AE than in Spanish (Bradlow, 1995).

1.3 Cross-Language Speech Perception in Early and Late Bilingual Adults

Factors found to affect accuracy of L2 speech perception include age of acquisition of the L2, use of the native and L2, the length of residence (LOR) in the L2 country, and the presence of noise in the L2 speech signal (Flege, 1991; Flege, Bohn, & Jang, 1997; Flege & MacKay, 2004; Flege et al., 1999; Flege, Schirru, & MacKay, 2003; Levy, 2009; Levy & Strange, 2008; Mack, 1989; Mayo, Florentine, & Buus, 1997; Morrison, 2002; Piske, Flege, MacKay, & Meador, 2002; Shi, 2010). The most important predictor of L2 speech perception is the age at which L2 is acquired (Flege & MacKay, 2004; Flege et al., 1999; Flege et al., 2003; Piske et al., 2002). Studies measuring early and late bilinguals' L2 vowel perception have shown that early bilinguals have an advantage in accurately perceiving L2 vowels. For example, Flege and MacKay (2004) examined the discrimination of Canadian-English vowels by native Canadian-English listeners and early and late Italian-English bilingual listeners. The early and late Italian-English bilinguals arrived in Canada at 2-13 and 15-26 years of age, respectively. Early and late Italian-English bilingual listeners who reported using Italian between 1% and 15% of the time were assigned to the "low-continued use" of their native language group and those who reported using Italian between 25% and 100% of the time were assigned to the "high-continued use" of their native language group. The Canadian-English vowel contrasts /i-ɪ/, /ɛ-æ/, and /æ-ʌ/ were tested in a discrimination task. Native Canadian-English and early Italian-English bilingual listeners with "low-continued use" of their native language discriminated Canadian-English vowels more accurately than early Italian-English bilingual listeners with "high-continued use" of their native language and both groups of late Italian-English listeners. Contrary to Flege et al.

(2004), in Flege et al.'s (1999) study, continued use of the native language did not affect early Italian-English bilingual listeners' perception of Canadian-English vowels when presented with a similar discrimination task. However, consistent with Flege et al. (2004), early Italian-English bilingual listeners performed more similarly to native Canadian-English listeners than to late Italian-English bilingual listeners, suggesting that age of L2 acquisition influences L2 vowel discrimination in Italian-English bilingual listeners.

Findings conflict regarding whether early bilinguals, defined here as individuals who learn an L2 pre-puberty, can perceive L2 vowels in a native-like manner. Mack (1989) examined native AE monolingual listeners' and early French-English bilingual listeners' identification of synthetic AE /i/ and /ɪ/ vowels (/i/ is a French vowel, whereas /ɪ/ is not). Early French-English bilinguals had acquired French and English prior to 8 years of age and either acquired French or English as their L2 at a mean age of 4.5 years. Results indicated that AE monolingual listeners identified more vowels as AE /i/ than did early French-English bilingual listeners, who perceived more vowels as /ɪ/, suggesting different perceptual patterns for AE monolinguals and early French-English bilingual listeners.

In contrast, Flege et al. (1999) did find native-like discrimination by early L2 learners. Early Italian-English bilingual listeners and native Canadian-English monolingual listeners were presented with three vowel stimuli on each trial of a Canadian-English and Italian vowel discrimination task. Listeners were instructed to identify the vowel that was different from the others. Early Italian-English bilinguals were first exposed to English at 7 years of age upon arrival to Canada. The vowel

contrasts examined were two Canadian-English vowels (/æ-ʌ/, /ʌ-ɒ/, /i-ɪ/, /u-ʊ/) one Canadian-English and one Italian vowel (/æ-a/, /ʌ-a/, /ʊ-o/, /e-eˈ/), and two Italian vowels (/u-o/, /e-a/, /u-i/). The early Italian-English bilingual listeners' performance did not significantly differ from Canadian-English monolingual listeners. Thus, early Italian-English bilingual listeners had presumably established new categories for vowels found in the L2.

The different findings between studies may be due to the use of different experimental procedures, stimuli, and ages of participants. For instance, Mack (1989) examined the identification and discrimination of vowels on a synthetic continuum. Flege et al. (1999), on the other hand, conducted a categorial discrimination test with natural tokens of each vowel category. Additionally, the early bilinguals examined by Mack (1989) had learned their L2 prior to 8 years of age, and were a mean age of 21 years at the time of testing. The participants examined in Flege et al. (1999) were first exposed to their L2 at 7 years of age and were a mean age of 48 at the time of testing. The participants in Flege's study were more likely to have used their L2 for a longer period of time, which may have impacted results.

1.4 Late Spanish-English Bilingual Adults' Speech Perception

Length of residence (LOR) in the L2 country has been examined as a factor impacting the accuracy of L2 vowel perception by late Spanish-English bilingual listeners. Morrison (2002) examined Canadian-English vowel identification by late Spanish-English bilingual listeners. Spanish-English bilingual listeners had not been immersed in a language other than Spanish prior to their arrival in Canada at the age of at least 16 years and had one month to six months of exposure to the L2 (Canadian-

English). Late Spanish-English bilingual listeners and native Canadian-English listeners were instructed to match Canadian-English target words /bɪt/, /bit/, /bɪd/, and /bid/ to pictures representing the words. One month after their arrival in Canada, identification of Canadian-English vowels /ɪ/ and /i/ was poor. By 6-months after their arrival, identification of these vowels matched that of Canadian-English listeners. According to Morrison (2002), Spanish listeners had presumably assimilated Canadian-English /i/ to Spanish /i/ and established a new category for Canadian-English /ɪ/.

Flege et al. (1997) also examined the impact of LOR on the perception of AE vowels by Spanish-English bilingual listeners. Participants consisted of one group of native AE listeners and two groups of late Spanish-English bilingual listeners. Late Spanish-English bilingual listeners arrived to the US at a mean age of 25 years and were assigned to "experienced" or "inexperienced" subgroups based on their LOR (9 years versus 0.4 years). Listeners were instructed to identify AE vowels by selecting the word "beat" or "bit" in the AE /i/ - /ɪ/ synthetic continuum or "bet" or "bat" in the AE /ɛ/ - /æ/ synthetic continuum to indicate the vowel heard. Late Spanish-English bilingual "inexperienced" listeners relied more on vowel duration, whereas late Spanish-English bilingual "experienced" listeners relied more on spectral cues to identify AE vowels, much like native AE listeners. Therefore, late Spanish-English bilingual listeners' identification of AE vowels became more native-like as a function of a longer LOR.

Findings from Flege (1991) further support the effect of LOR on the identification of natural AE vowels by Spanish monolinguals and Spanish-English bilinguals. Spanish monolingual listeners and two groups of late Spanish-English bilingual listeners who differed in LOR (4 months versus 10 years) were instructed to identify natural AE vowels

/i/, /ɪ/, /ɛ/, and /æ/ in “beat”, “bit”, “bet”, and “bat” according to their Spanish equivalents by circling one of the five letters (“a”, “e”, “i”, “o”, “u”). They were instructed to use the label “none” if they judged the AE vowel not to be a Spanish vowel. Spanish monolingual listeners identified AE /i/ and /ɪ/ as Spanish /i/ (94%, 68%). AE /ɛ/ was most often identified as Spanish /e/ (81%), but also as Spanish /a/ (13%). AE /æ/ was most often identified as Spanish /a/ (71%) and at times as Spanish /e/ (17%). The difference in performance between the groups of Spanish-English bilingual listeners was not statistically significant. Both groups of Spanish-English bilingual listeners identified AE /i/ as Spanish /i/. AE /ɪ/ was most often identified as Spanish /e/ (39%), /i/ (36%), and as the “none” (21%) category. AE /ɛ/ was most often identified as Spanish /e/ (44%), /a/ (39%), and was sometimes given the label “none” (13%). AE /æ/ was most often identified as Spanish /a/ (82%) and sometimes as “none” (12%). Overall, late Spanish-English bilingual listeners used the label “none” more often than Spanish monolingual listeners to identify AE vowels. Additionally, late bilingual listeners with a longer LOR in the US used the label “none” more often than those late bilingual listeners with a shorter LOR in the US. Findings indicate that identification of AE vowels becomes more native-like as a function of LOR (4 months versus 10 years).

The dialect of the non-native language may also have an effect on the way vowels are perceived by non-native listeners. For example, Escudero and Chládková (2010) investigated the perception of Standard Southern British English (SSBE) and AE vowels by Peruvian Spanish monolingual listeners. Listeners were instructed to identify synthetic SSBE and AE vowels /i/, /ɪ/, /u/, /ʊ/, /ɛ/, /ʌ/, /ɔ/, /æ/, and /ɑ/ with one of the Spanish response categories (“a”, “e”, “i”, “o”, “u”) presented orthographically on a

computer screen. Listeners were told that the Spanish vowels heard were taken from recordings of running speech and may at times sound like poor examples of the vowels. Listeners assimilated AE and SSBE vowels to different Spanish vowels and at times these vowels were assimilated to single or multiple Spanish vowels. For instance, listeners assimilated AE /ɪ/, /ɛ/, and /æ/ to Spanish /e/ (above 70%), whereas SSBE /ɪ/ and /ɛ/ were assimilated to Spanish /e/ (30%-70%, above 70%) and SSBE /æ/ to Spanish /a/ (above 70%). Additionally, listeners assimilated AE /ɔ/ and /ʊ/ to Spanish /o/ and AE /u/ to Spanish /u/ above 70% of the time, whereas SSBE /ɔ/ was assimilated to Spanish /o/ and SSBE /ʊ/ and /u/ to Spanish /u/ between 30-70% of the time. AE /ɑ/ was assimilated to Spanish /a/ (above 70%), whereas SSBE /ɑ/ was assimilated to both Spanish /a/ and /o/ (30%-70%). Lastly, AE /ʌ/ was assimilated to Spanish /a/ and /o/ (30%-70%), whereas SSBE /ʌ/ was assimilated to Spanish /a/ (above 70%). Therefore, results indicate that listeners' perception of non-native vowels may be influenced by the dialectal variations in the non-native language.

Such differences were also observed in the perception of the (synthetic) Scottish-English /i-ɪ/ contrast in isolation in a forced identification task (Escudero and Boersma, 2004). Participants consisted of four groups: native Scottish-English listeners, native Southern British-English listeners, native Spanish listeners learning Scottish English and native Spanish listeners learning Southern British-English. Listeners were instructed to press a button indicating a picture of a "sheep" or "ship", depending on the Scottish-English vowel they heard in the target word. Spanish listeners learning Scottish-English and native Scottish-English listeners relied on similar spectral cues. However, Spanish listeners learning Southern British-English used durational cues, a strategy that was not

used by native Southern British-English listeners. Therefore, use of acoustic cues in English vowel identification by Spanish listeners learning English may vary as a function of the English dialect and, at times, Spanish listeners may use perceptual strategies not exhibited by English listeners. Escudero and Boersma (2004) proposed that the differences found in the study may be due to the different stages L2 learners go through as a function of the dialect of English that they are learning.

In addition to the dialect of the L2 language, the dialect of the native language may result in differences in L2 vowel perception (Morrison, 2008). Monolingual Mexican-Spanish and monolingual Peninsular-Spanish listeners were presented with stimuli containing synthetic Western Canadian-English /i/ and /ɪ/ vowels. Listeners were instructed to indicate which native Spanish vowel sounded most like the synthetic Western Canadian-English vowels. They were given choices of Spanish /i/ and /e/ vowels in a /bVp/ context. Western Canadian- English /i/ was identified as Spanish /i/ by Spanish listeners of both dialects. However, Western Canadian-English /ɪ/ was identified by two thirds of the Mexican-Spanish listeners as Spanish /i/, whereas one third of the Mexican-Spanish listeners identified it as Spanish /e/. Almost all of the Peninsular-Spanish listeners identified Western Canadian-English /ɪ/ as Spanish /e/. In summary, results from cross-dialectal studies indicate that the dialect of the native language and L2 may influence the manner that L2 vowels are perceived.

1.5 Bilingual Speech Perception in Noise

In addition to the age of L2 acquisition and the dialect of the native language and L2, the presence of noise can influence L2 speech perception (Mayo et al.,1997; Shi, 2010). Mayo et al. (1997) investigated the speech perception in noise of three groups of

Spanish-English bilingual listeners and one group of native monolingual AE listeners. Spanish was the native language of the Spanish-English bilingual listeners. The first group of Spanish-English listeners acquired Spanish and AE at infancy, the second group learned AE before the age of 6, and the third group learned AE after the age of 14. Listeners were presented with sentences in noise from the Speech Perception in Noise (SPIN) test (Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984; Kalikow, Stevens, & Elliott, 1977). They were instructed to state the target word at the end of every sentence. Some sentences provided semantic cues to help determine the final word in the sentence while others did not contain such cues. Results indicated that native AE monolingual listeners and both groups of early Spanish-English bilingual listeners performed more accurately than late Spanish-English bilingual listeners. Thus, the negative impact of noise on the listeners' L2 speech perception is greater for late bilinguals than for early bilinguals.

1.6 Summary

Accurate perception of vowels is crucial to understanding a language. Listeners' perceptual performance may be affected by differences in native and L2 vowel inventories (Best & Tyler, 2007), age of L2 acquisition, LOR in the L2 country, dialect of the native and L2 language, and presence of noise in the L2 speech signal.

Given the increasing number of Hispanic immigrants who are entering the US (US Census Bureau, 2011) and are learning AE as their L2, information about the effects of age of L2 acquisition and an analysis of the perceptual relationship between vowels in two commonly spoken languages (AE and Spanish) are needed. To the author's knowledge, all of the previously reported studies on the relationship between AE and

Spanish vowels have been performed on late Spanish-English bilingual listeners. Additionally, this has been investigated mostly using synthetic speech (Escudero & Boersma, 2004; Flege et al., 1997; Morrison, 2002) and in a handful of studies using natural speech (Flege, 1991; Flege, Munro, & Fox, 1994; Fox, Flege, & Munro, 1995). Synthetic and natural speech may be perceived differently as indicated by Kangas and Allen's (1990) finding that adult listeners repeated words in their native language (AE) more accurately when stimuli were natural speech tokens than when they were synthesized tokens. Therefore it cannot be assumed that results from synthetic speech will also apply to natural speech. Furthermore, to the author's knowledge, no studies exist on the perception of AE vowels in the context of noise, which represents everyday conditions in which speech perception takes place. Listeners have difficulty perceiving speech, especially L2 speech, accurately in noisy environments (Adachi, Akahane-Yamada, & Ueda, 2006; Broersma & Scharenborg, 2010; Garcia Lecumberri et al., 2010; Ueda, Akahane-Yamada, & Komaki, 2002; von Hapsburg, Champlin, & Shetty, 2004). The perception of AE vowels by late Spanish-English bilingual listeners has been examined in quiet conditions. A study on the perception of AE vowels in natural speech and in the presence of noise by early and late Spanish-English bilinguals is needed in order to shed light on the effects of L2 acquisition on the perception of AE vowels in everyday conditions.

Information on the perception of AE vowels by Spanish-English bilinguals may assist professionals working with this population. Intervention programs might be developed to improve their perception of challenging AE vowels. This study may help serve as a foundation for future studies that may investigate perceptual challenges

experienced by Spanish-English bilingual children with and without communication disorders.

1.7 The present study: questions and predictions

The present study addressed the following research questions:

1. Does perceptual assimilation of native AE vowels vary as a function of:
    a. the listener's language background (early vs. late bilingual)?
    b. the particular vowel?
2. Does discrimination accuracy of native AE vowels vary as a function of:
    a. the listener's language background (native AE monolingual vs. early vs. late bilingual)?
    b. the particular vowel?
3. Does identification of native AE vowels in noise vary as a function of:
    a. the listener's language background (native AE monolingual vs. early vs. late bilingual)?
    b. the particular vowel?
4. Do early and late Spanish-English bilingual listeners' perceptual assimilation patterns predict their categorial discrimination of American English vowels?

The following predictions were made in reference to the research questions posed:

Question 1a: Does perceptual assimilation of native AE vowels vary as a function of the listener's language background?

Predictions: Previous research has focused on the effect of age of language acquisition on vowel discrimination accuracy by early and late bilinguals (Flege &

MacKay, 2004; Flege et al., 1999; Flege et al., 2003; Piske et al., 2002). Since assimilation type patterns predict discrimination accuracy (Best, 1995), it was expected that early Spanish-English bilingual adult listeners would display more native-like perceptual assimilation patterns than late Spanish-English bilingual adult listeners as suggested by previous results in cross-language speech discrimination tasks (Flege & MacKay, 2004; Flege et al., 1999; Flege et al., 2003; Levy, 2009a; Levy, 2009b; Piske et al., 2002). However, it was unclear whether the early bilinguals would demonstrate native-like perceptual assimilation patterns (Flege et al.,1999; Mack,1989).

Question 1b: Does perceptual assimilation of native AE vowels vary as a function of the particular vowel?

Predictions: Similar assimilation type patterns that were revealed in Flege's (1991) study were predicted in the present study. For example, Flege (1991) found that late Spanish-English bilinguals most often identified AE /i/ as Spanish /i/. AE /æ/ was most often identified as Spanish /a/ (82%) and sometimes as "none" (12%). They identified AE /ɪ/ most often as Spanish /e/ (39%), /i/ (36%), and as the "none" (21%) category. Lastly, they identified AE /ɛ/ most often as Spanish /e/ (44%), /a/ (39%), and they sometimes identified it as "none" (not fitting any Spanish category) (13%).

Similar assimilation patterns were found in pilot data collected for the present study and were predicted for the present study. For instance, in the pilot study AE vowels /æ/ and /ɑ/ were most often assimilated to Spanish /a/, AE vowel /i/ to Spanish /i/, and AE vowel /ɛ/ to Spanish /e/. AE vowel /ɪ/ was assimilated to Spanish /e/ by early bilinguals. However, late bilinguals mostly assimilated AE vowel /ɪ/ to Spanish /e/ and

/i/. AE vowel /ʌ/ was assimilated to Spanish /a/, /e/, and /o/ by early bilinguals and /a/ and /o/ by late bilinguals. AE vowel /ɛ/ was mostly assimilated to Spanish /e/ by early bilinguals and to Spanish /e/ and /a/ by late bilinguals. Control vowel AE /o/ was assimilated to Spanish /o/.

Question 2a: Does discrimination accuracy of native AE vowels vary as a function of the listener's language background?

Predictions: It was predicted that early Spanish-English bilingual adult listeners would discriminate AE vowels more accurately than late Spanish-English bilingual adult listeners, as suggested by previous research in cross-language speech perception (Flege & MacKay, 2004; Flege et al., 1999; Flege et al., 2003; Piske et al., 2002). For example, Flege and MacKay (2004) examined the discrimination of Canadian-English vowels by native Canadian-English listeners and early and late Italian-English bilingual listeners. Native Canadian-English and early Italian-English bilingual listeners discriminated Canadian-English vowels more accurately than late Italian-English bilingual listeners, suggesting that age of L2 acquisition influences L2 vowel discrimination in Italian-English bilingual listeners.

Question 2b: Does discrimination accuracy of native AE vowels vary as a function of the particular vowel?

Predictions: It was predicted that L2 vowels would be discriminated accurately if they were assimilated to two different native language vowels in the present study (Best

& Tyler, 2007). L2 vowels would be discriminated less accurately if both L2 vowels were assimilated to instances of a single native language vowel (Best & Tyler, 2007).

Results from the pilot data for the present study revealed high discrimination accuracy for vowel contrast /ɪ-i/ for early and late Spanish-English bilinguals. Late Spanish-English bilinguals had the most difficulty discriminating AE vowel contrast /ʌ-æ/, followed by /ʌ-ɑ/, /æ-ɑ/, /ɪ-ɛ/, /ɪ-i/, and the control pair /ɑ-i/. Late bilinguals assimilated the vowels in each of the contrasts /ʌ-æ/ and /ʌ-ɑ/ to a single L1 vowel (Spanish /a/), and, as predicted, the vowels in each contrast were poorly discriminated. Vowel contrast /i-ɪ/ was relatively easy to discriminate for late bilinguals as each AE vowel in this contrast was assimilated to two different L1 vowels (Spanish /i/ and /e/).

Question 3a: Does identification of native AE vowels in noise vary as a function of the listener's language background?

Predictions: According to pilot data that were collected for the present study, AE monolinguals performed more accurately (81%) than early bilinguals (65%) and late bilinguals (40%). Similar results were predicted in the present study.

Question 3b: Does identification of native AE vowels in noise vary as a function of the particular vowel?

Predictions: It was expected that the vowels that were assimilated to two different native language vowels would be identified more accurately than vowels that were assimilated as instances of a single native language vowel in the present study. For example, AE vowels /æ/ and /ɑ/ were most often assimilated to Spanish /a/. Therefore it

was expected that these AE vowels would be poorly identified. However, AE vowel /i/ was assimilated to Spanish /i/ and AE vowel /ɛ/ to Spanish /e/. It was therefore expected that these AE vowels would be identified more accurately.

Question 4: Do early and late Spanish-English bilingual listeners' perceptual assimilation patterns predict their categorial discrimination of American English vowels?

Predictions: Results of the pilot data collected for this study indicated that Spanish-English bilingual listeners' perceptual assimilation patterns predicted their categorial discrimination of American English vowels. When late bilingual listeners assimilated L2 vowels to a single L1 vowel category, their discrimination accuracy was lower. For instance, vowel contrasts /ʌ-ɑ/ and /ʌ -æ/ were the most difficult to discriminate for late bilinguals. Late bilinguals assimilated the vowels in each of these contrasts to a single L1 vowel (Spanish /a/), and as expected the vowels in each contrast were difficult to discriminate. However, higher discrimination accuracy was revealed when L2 vowels were assimilated to distinct L1 vowels. For example, vowel contrast /i-ɪ/ was relatively easy to discriminate for late bilinguals, as expected, as each AE vowel in this contrast was assimilated to two different L1 vowels (Spanish /i/ and /e/).

Chapter 2. Method

2.1 Perceptual Assimilation task

2.1.1 Stimulus materials and procedures

The AE vowels /i/, /ɪ/, /ɛ/, /ʌ/, /æ/, /ɑ/, and /o/ were selected for the perceptual assimilation task of the current study. The vowel /o/ was used as a control vowel. Vowels were presented in a /gəbVpə/ context in the carrier phrase "five /gəbVpə/ this

time." Consonants /b/ and /p/ preceded and followed the target vowel because these consonants do not involve articulation of the tongue, thus minimizing any coarticulatory influence on the target vowels (Levy, 2009; Strange, Weber, Levy, Shafiro, Hisagi, & Nishi, 2007). Nonsense words were selected rather than real words to decrease any lexical effects (Neuman & Hochberg, 1983). A carrier phrase was used rather than vowels or words in isolation because phrases are more representative of everyday speech than are words or vowels in isolation.

Three female native monolingual AE talkers from the New York regional area were recorded producing the nonsense word /gəbVpə/ embedded in the carrier phrase "Five gəbVpə this time". Talkers were required to be monolingual speakers of AE and have minimal exposure to other languages and have no history of speech or language disorders. They passed a bilateral hearing screening at 20dB at 500, 1000, 2000 and 4000 Hz. A language background questionnaire was completed by all talkers.

Talkers were recorded in a sound-treated booth in the Speech Production and Perception Lab at Teachers College, Columbia University. Output was recorded through a Shure (SM58) microphone placed approximately 15 cm from the talker's mouth and passed through a Shure (Prologue 200M) mixer to a Turtle Beach Rivera sound card of a Dell Pentium desktop computer using Soundforge™ 8.0 software, with a sample rate of 22,050 Hz, 16-bit resolution, on a mono channel. (See Appendix B for flowchart of recording equipment.) The experimenter was in the adjoining room and provided the talker with directions using an intercom. Talkers read 4 lists, producing 10 utterances (Five gəbVpə this time) on each list, which contained stimuli with 9 AE vowel targets. (See Appendix A for protocol for talkers.) Talkers were instructed to read each utterance

as if talking to a good friend. Utterances on lists were randomized and the first utterance and the last utterance contained the same target vowel. In order to control for list-final intonation effect, the final utterance was discarded (Strange et al., 2007). The experimenter listened to the recording input via Sennheiser HD 280 pro headphones. If an utterance contained irregular rate, prosody, vocal quality, pronunciation, or noise, the talker was instructed to repeat the utterance. For each vowel the second and third recording were used unless a recording was determined by the primary investigator to have noise or other distraction. Multiple tokens of the utterances were used to obtain information on categorial perception rather than physical discrimination (Gottfried, 1984). Stimuli were entered into the Paradigm software program (Tagliaferri, 2001).

Stimuli were presented via Sennheiser HD 280 pro headphones during the experimental tasks. Listeners were presented with the carrier phrase "Five /gəbVpə/ this time". Listeners were instructed to click on the Spanish key word that contains the vowel that sounds most like the second vowel sound in /gəbVpə/. (See Appendix E for instructions.) Response options were displayed on the computer monitor and included the nonsense words "bapo", "bepo", "bipo", "bopo", "bupo" representing the Spanish vowels /a/, /e/, /i/, /o/, and /u/. Listeners then heard the stimulus again and was asked to rate the vowel on a scale from 1-9, with (1) indicating "least Spanish-like" and (9) indicating "most Spanish-like." Participants were instructed to use the entire spectrum of the scale. (See Appendix F for diagram of computer screen.) Listeners heard 6 blocks, 5 blocks of 50 trials and 1 block of 47 trials, totaling 297 responses (6 vowels x 3 talkers x 3 tokens x 5 repetitions + 27 control).

Prior to the experimental trials, listeners completed three procedures: a key word familiarization, task familiarization, and stimulus familiarization procedure. In a key word familiarization procedure, listeners were instructed to read the 5 key words ("bapo", "bepo", "bipo", "bopo", "bupo") aloud to the examiner. Errors were discussed and corrected. Listeners were then presented with AE phrases "Five gəbVpə this time" containing AE vowels /o/, /e/, and /u/ in a task familiarization procedure. Listeners were instructed to listen to the second vowel of the American English nonsense word (e.g. the "ee"in gabeepa) in the phrase and choose the Spanish keyword ("bapo", "bepo", "bipo", "bopo", "bupo") that is a good example of that sound. Listeners were then presented with a stimulus familiarization procedure that included AE phrases "Five gəbVpə this time" containing AE vowels /i/, /ɪ/, /ɛ/, /ʌ/, /æ /, and /ɑ/. Response options were displayed on the computer monitor and included the nonsense words "bapo", "bepo", "bipo", "bopo", "bupo" representing the Spanish vowels /a/, /e/, /i/, /o/, and /u/. Listeners heard the stimulus again and were asked to rate the vowel on a scale from 1-9, with (1) indicating "least Spanish-like" and (9) indicating "most Spanish-like." Each listener completed a 10-trial task familiarization block and a 6-trial stimulus familiarization block consisting of one representation of each stimulus. Data from these blocks were discarded.

2.2 Categorial Discrimination Task

2.2.1 Stimulus materials and procedures

In this experiment, test materials contained the same stimuli as used in the perceptual assimilation task; however, noise was added to stimuli. Speech-shaped noise consisting of a -2 dB signal-to-noise ratio was added to stimuli using the Praat v. 5.2.22

program, based on the findings of the pilot study. The following 6 vowel contrasts were tested: /i-ɪ/, /ɪ-ɛ/, /ʌ-ɑ/, /ʌ-æ /, /æ-ɑ/ and control contrast /ɑ-i/.

For each trial, stimuli were produced by three different talkers, with the order of talkers randomized. Three stimuli were presented in AXB trials via Sennheiser HD 280 pro headphones. For each contrast, half the "same" tokens preceded the 2nd stimulus, half went after it. Participants were instructed to click on "1" if the vowel in the second phrase was the same as the one in the first phrase and click on "3" if the vowel in the third phrase was the same as the one in the second phrase. (See Appendix H for instructions; see Appendix I for diagram of computer screen.) Four blocks, including 3 blocks of 50 trials and 1 block of 54 trials, totaling 224 responses (5 vowel contrasts x 3 talkers x 3 tokens x 4 repetitions + 24 control contrasts) were presented.

Prior to testing, task and stimulus familiarization procedures were performed. Participants were instructed to click on "1" if the vowel in the second phrase was the same as the one in the first phrase and click on "3" if the vowel in the third phrase was the same as the one in the second phrase. AE vowel contrasts (/ʌ -i/, /u-æ/, and /i-o/) in a /gəbVpə/ context in the carrier phrase "five /gəbVpə/ this time" in an AXB paradigm were presented. A stimulus familiarization procedure contained the same vowel contrasts used in the experiment. Each listener completed a 15-trial task familiarization block and a 22-trial stimulus familiarization block. Data from these blocks were discarded.

2.3 Identification Task

2.3.1 Stimulus materials and procedures

In this experiment, test materials contained the same stimuli as used in the perceptual assimilation task; however, speech-shaped noise consisting of a -2 dB signal-to-noise ratio was added.

Listeners were presented with the carrier phrase "Five /gəbVpə/ this time." They were instructed to click on the key word response from a choice of words on the computer monitor. These included the nonsense words "gabeepa", "gabippa", "gebeppa", "gabUpa", "gabappa", "gaboppa", "gaboapa", "gabuppa", "gabaypa", "gaboopa". (See Appendix K for instructions; see Appendix L for diagram of computer screen.) Listeners heard 6 blocks, 5 blocks of 50 trials and 1 block of 47 trials, totaling 297 responses (6 vowels x 3 talkers x 3 tokens x 5 repetitions + 27 control).

Prior to the experimental trials, listeners completed a task familiarization procedure. Listeners were presented with AE phrases "Five gəbVpə this time" containing AE vowels /o/, /e/, and /u/. Listeners were instructed to click on the key word response from a word set on the computer monitor and included the nonsense words "gabeepa", "gabippa", "gebeppa", "gabUpa", "gabappa", "gaboppa", "gaboapa", "gabuppa", "gabaypa", "gaboopa". Each listener completed a 10-trial task familiarization block. Data from this block were discarded.

2.4 Stimulus Verification

For purposes of stimulus verification, three monolingual native speakers of AE identified all tokens of each vowel stimulus (/i/, /ɪ/, /ɛ/, /ʌ/, /æ /, /ɑ/, and /o/) in a -2dB signal-to-noise ratio condition in an identification task. Listeners were presented with the

phrase “five /gəbVpə/ this time” and chose a keyword response from the word set (gabeepa, gabippa, gebeppa, gabUpa, gabappa, gaboppa, gaboapa, gabuppa, gabaypa, gaboopa). Tokens that were identified with 100% accuracy were used in the experiment.

2.5 Acoustic Analysis

Acoustic analysis was performed using Praat v. 5.2.22. Each vowel token was obtained after calculating the beginning and end of each phrase (“five /gəbVpə/ this time”). The beginning of each phrase was determined by the first mark of frication energy for /f/ in “five”. The end of each phrase was determined by the end of the voicing bar for /m/ in “time”. The onset of the syllable containing the target vowel was determined by the release burst of the /b/, which was noted by a spike of acoustic energy on the spectrogram. The syllable offset was determined by the beginning of closure of /p/, which was noted by a decrease in periodic energy in the higher formants on the spectrogram. Values for the first two formants (F1, F2) for a 25 ms window were calculated at the temporal midpoint (50% point) between onset and offset of the syllable. A comparison of the acoustic vowel categories of AE and Castilian Spanish are shown in Figure 1. The squares in the figure represent the average F1 and F2 frequencies of the AE target vowels used in the experiment. The circles in the figure represent mean F1 and F2 frequencies of Castilian Spanish tokens taken from Bradlow’s (1995) cross-linguistic study of AE and Castilian Spanish vowels.

2.6 Participants

Three groups of listeners participated in the experiment: 10 native monolingual AE adults, 12 “early” Spanish-English bilingual adults, and 12 “late” Spanish-English bilingual adults. According to previous studies, the terms “early bilingual” and “late

bilinguals" refer to individuals who have learned an L2 pre-puberty or post-puberty (Flege & MacKay, 2004; Flege et al.,1999; Mack ,1989). Both bilingual groups performed all tasks. However, the monolingual group only performed the categorial discrimination and identification tasks. Participants were between the ages of 18-48. (See Appendix M for participant characteristics.) All listeners completed a language background questionnaire. (See Appendix N for language background questionnaire for monolingual English participants; see Appendix O for language background questionnaire for bilingual participants.) Listeners were given Institutional Review Board (IRB) consent forms for review and signature. All listeners passed a bilateral hearing screening at 20 dB at 500, 1000, 2000 and 4000 Hz and had no reported history of a speech or language disorder.

The native monolingual AE group listeners were born in AE-speaking households in the US and had minimal Spanish experience. The "early" bilingual group listeners were born in a Spanish speaking country and immigrated to the US prior to 12 years of age at which time they learned AE. These participants were raised in a monolingual Spanish household and had no English exposure in their native country. "Late" bilinguals were born in a Spanish speaking country and raised in a monolingual Spanish household. They immigrated to the US no earlier than 14 years of age. They reported no AE instruction or interaction with AE speakers with any regularity prior to this age. Length of residence in the US and use of L2 was not used as selection criterion.

Chapter 3. Results

A total of 21,192 responses were collected from 34 listeners (501 trials from each AE monolingual listener and 798 trials from each early and late bilingual listener).

Descriptive and nonparametric statistics were performed on all data. All statistical analyses were performed using R software, version 2.15.1, the 1me4 package (R Development Core Team, 2010).

To determine whether perceptual assimilation patterns, discrimination and identification accuracy differed as a function of language background and particular vowel in this study, results were analyzed using a mixed effects logistic regression model. Mixed effects model analyses have been reported to give more reliable and robust results for categorical outcome variables (e.g., the forced-choice variables used in this study) than analysis of variance methods used in speech perception studies (Ferguson, 2012; Jaeger, 2008). These models contain both fixed and random effects. In this study, fixed effects included vowels and group. Listeners were considered random effects as they are thought of as a random selection of a much larger population.

3.2. Perceptual Assimilation of AE vowels: language background and particular vowel effects

In response to the first research question, regarding language background effects on perceptual assimilation of AE vowels, early bilingual listeners demonstrated similar assimilation patterns to late bilingual listeners for all vowels. Tables 1 and 2 show the Spanish vowel (perceptual assimilation) responses selected by early bilingual (EB) and late bilingual (LB) listeners for the AE vowel stimuli presented. Table 3 displays the modal Spanish vowels chosen by the early and late bilingual listener groups for all AE vowel stimuli presented. The left-hand column lists the AE vowel stimuli, followed by the second column, which lists the overall modal Spanish responses chosen. The column labeled “Mode percent chosen” indicates the overall percentage of trials that particular

Spanish response was chosen by early and late bilingual listeners. The "Median Rating" indicates the median of goodness ratings from 1 (least Spanish-like) to 9 (most Spanish-like) of all of the trials on which bilingual listeners selected the modal response category.

As the tables show, early and late bilingual listeners perceptually assimilated AE vowels to Spanish vowels that are acoustically similar to the AE vowels. For example, early and late bilingual listeners assimilated AE front vowel /ɪ/ to both Spanish front /e/ (early bilinguals: 49%, late bilinguals: 49%) and Spanish front /i/ (early bilinguals: 50%, late bilinguals: 50%) and AE front vowel /ɛ/ to Spanish front /e/ (early bilinguals: 94%, late bilinguals: 87%). For the two groups of listeners, modes were similar to each other for AE vowels /ɪ/ (50%, 50%) and /ɛ/ (94%, 87%), suggesting that perceptual assimilation of these vowels did not vary as a function of language background. Early and late bilingual listeners assimilated AE vowels /æ/ (early bilinguals: 92%, late bilinguals: 82%) and /ɑ/ (early bilinguals: 83%, late bilinguals: 75%) primarily to Spanish central vowel /a/. Spanish mode percentages for AE vowels /æ/ and /ɑ/ increased as a function of language background, suggesting that earlier age of L2 acquisition was associated with more stability in vowel representation for these vowels.

Early and late bilingual listeners assimilated AE central vowel /ʌ/ to Spanish central and back vowels. For example, early bilingual listeners most often assimilated AE /ʌ/ to Spanish /u/ (42%), Spanish /a/ (30%), and Spanish /o/ (24%) and late bilingual listeners assimilated AE /ʌ/ to Spanish /a/ (53%) and Spanish /o/ (39%). The Spanish modal choice for AE /ʌ/ differed for early and late bilingual listeners (/u/, /a/, respectively). Additionally, AE vowel /ʌ/ received a relatively low modal percentage score (42%, 53%) by early and late bilingual listeners respectively, indicating difficulty or inconsistency in

categorizing this vowel.

Overall, median goodness ratings for all vowels increased from early to late bilingual listeners, suggesting that late bilingual listeners perceived AE vowels as more like their native vowels than early bilingual listeners. Furthermore, the majority of AE vowels (/ɪ/,/ɛ/, /æ/, /ɑ/, /ʌ/, /o/) received high median goodness ratings (8,5,8,9,8,9, respectively) by late bilingual listeners suggesting that late bilingual listeners accepted AE vowels as good instances of their Spanish category and were possibly less attuned to the differences between these AE and Spanish vowels than early bilingual listeners (median goodness ratings: 6,1,3,7,7,6). Mixed effects logistic regression indicated a statistically significant difference in goodness ratings for early and late bilingual listeners ($p = .049$) (see Appendix P).

When early and late bilingual listeners' responses were compared for each AE vowel stimulus presented, a mixed effects logistic regression indicated no statistically significant difference in responses for AE /i/, /ɪ/, /ɑ/, or /o/ (see Appendix Q). However, a statistically significant difference in responses was evident for AE vowel /ɛ/, /æ/, and /ʌ/ stimuli. For example, a significant difference between early and late bilingual listeners' responses to AE vowel /ɛ/ was found for their Spanish vowel response /a/ ($p = .018$) and for /e/ ($p = .034$). Likewise, a significant difference between early and late bilingual listeners' responses to AE /ʌ/ was found for their Spanish vowel response /a/ ($p = .015$) and /u/ ($p < .001$). Lastly, a significant difference or a trend (i.e., a difference approaching significance) between early and late bilingual listeners' responses to AE vowel /æ/ was found for their Spanish vowel response /a/ ($p = .009$), /e/ ($p = .051$), and /o/ ($p = .054$).

3.3. Categorial Discrimination of AE vowels: language background and particular vowel effects

In response to the second research question, regarding language background and particular vowel effects on categorial discrimination, results are provided in Figure 2 which displays the percent correct for each vowel contrast by each listener group. The AE vowel contrast is along the X-axis and the percent correct with error bars representing standard error of the mean in percent is along the Y-axis. Overall, discrimination accuracy was highest for monolingual AE listeners (mean accuracy = 97%), followed by early bilingual (mean accuracy = 80%) and late bilingual listeners (mean accuracy = 66%). Mixed effects logistic regression confirmed that monolingual listeners performed significantly more accurately than early and late bilingual listeners ($z = -6.24$, $p < .001$ and $z = -9.21$, $p < .001$ respectively), and early bilingual listeners performed more accurately than late bilingual listeners ($z = -3.45$, $p = .001$) (see Appendices R).

As seen in the graph in Figure 2, monolingual AE listeners performed close to ceiling for all vowel contrasts: /i-ɪ/ (99%), /ʌ-æ/ (98%), /ɪ-ɛ/ (96%), /ʌ-ɑ/ (96%), and /æ-ɑ/ (94%). Accuracy in discriminating vowel contrasts varied for early and late bilingual listeners. For example, for early bilingual listeners, high discrimination accuracy was evident for vowel contrasts /ɪ-ɛ/ (91%) and /ɪ-i/ (86%), /ʌ-æ/ (77%), /ʌ-ɑ/ (73%), and /æ-ɑ/ (72%). Likewise, late bilingual listeners showed high discrimination accuracy for /ɪ-ɛ/ (78%) and /ɪ-i/ (74%), although they showed lower accuracy in discriminating vowel contrasts /æ-ɑ/ (60%), /ʌ-ɑ/ (59%), and /ʌ-æ/ (57%). Results from further analyses indicated significant differences between all listener groups (early bilinguals versus monolingual: $p < .001$; late bilinguals versus monolingual: $p < .001$; late bilinguals versus early bilingual: $p = .001$) for all vowel contrasts, as shown in Appendix S.

3.4. Identification of AE vowels: language background and particular vowel effects

With regard to language background and particular vowel effects on identification of AE vowels (Research Question 3), an overview of identification results is provided in Figure 3, which displays the AE vowels that early bilingual (EB) and late bilingual (LB) listeners chose for all AE vowel stimuli. The AE vowel stimuli are represented along the X-axis and the percent correct with error bars representing standard error of the mean is along the Y-axis. As expected, monolingual AE listeners identified AE vowels with the highest accuracy (mean accuracy = 90%), followed by early bilingual (mean accuracy = 67%), and late bilingual listeners (mean accuracy = 43%). Mixed effects logistic regression revealed that monolingual listeners performed significantly more accurately than early and late bilingual listeners ($z = -3.50$, $p < .001$ and $z = -7.08$, $p < .001$ respectively) and early bilingual listeners performed more accurately than late bilingual listeners ($z = -3.78$, $p < .001$) as shown in Appendix U.

As shown in the graph in Figure 3, AE vowels were identified with varying degrees of accuracy by listeners. AE high front vowel /i/ was identified the most accurately by all groups (monolinguals = 93%, early bilinguals = 82%, late bilinguals = 69%). Identification accuracy for AE back vowel /ʌ/ varied for listeners: monolinguals (89%), early bilinguals (60%) and late bilinguals (15%). Likewise, the identification accuracy of AE vowel /ɪ/ (monolinguals = 96%, early bilinguals = 75%, and late bilinguals = 41%) and AE vowel /ɛ/ (monolinguals = 92%, early bilinguals = 76%, and late bilinguals = 57%) varied for listeners. AE low back vowel /ɑ/ was identified the least accurately by all groups (monolinguals = 70%, early bilinguals = 39%, late bilinguals = 14%). Statistical analyses revealed significant difference in identification

accuracy for all vowels between groups of listeners except for AE vowel /i/ ($z = -1.33$, $p = .183$) between early bilingual and monolingual listeners (see Appendix U).

3.5. Predicting categorial discrimination accuracy based on perceptual assimilation patterns

A cross-language assimilation overlap method (Levy, 2009) was used in order to determine whether errors in categorial discrimination were related to the listeners' perceptual assimilation patterns (Research Question 4). A cross-language assimilation overlap score quantifies the extent to which perceptual assimilation for one vowel in a contrast overlaps with the perceptual assimilation of the other vowel in the contrast. This score is then compared to discrimination error scores to test the prediction by the PAM-L2 (Best & Tyler, 2007) that perceptual assimilation patterns (i.e., overlap in assimilation) predict discrimination accuracy (i.e., poorer discrimination). For example, if two AE vowels were assimilated to a single native category yielding a high assimilation overlap score and high discrimination errors, this would support the PAM-L2.

A cross-language assimilation overlap score and a categorial discrimination error score were calculated for each bilingual group as shown in Table 4. The left hand column lists the vowel contrast and is followed by the cross-language assimilation overlap score and discrimination percent error, arranged by overlap score in ascending order. Generally, the PAM-L2 (Best & Tyler, 2007) was supported in that AE vowels that were assimilated to the same native Spanish vowel in the perceptual assimilation task also showed higher discrimination errors than vowels that were assimilated to distinct categories. For example, in this study both segments /æ/ and /ɑ/ were perceptually assimilated to Spanish /a/ by early and late bilingual listeners, yielding a high cross-

language assimilation overlap score (79.8%, 75.9%, respectively) for vowel contrast /æ-ɑ/. As expected, the contrast was poorly discriminated by early and late bilingual listeners which resulted in high discrimination errors (28.5%, 40.1%, respectively). Conversely, vowel contrasts whose segments were assimilated to separate vowel categories were discriminated more accurately. This was observed for the control contrast /i-ɑ/ as each segment was perceptually assimilated to different categories (Spanish /i/ and /a/) during perceptual assimilation tasks, yielding a low percent of cross-language assimilation overlap (.92%, .73%, respectively) by early and late bilingual listeners. Thus, it was discriminated with fewer errors (2.4%, 3.1%, respectively).

The scatter plot in Figure 4 demonstrates the relationship between cross-language assimilation overlap and discrimination performance for all vowel contrasts. Along the x-axis are the cross-language assimilation overlap scores, while the y-axis represents the percent errors in discrimination. Each point in the graph demonstrates a bilingual group's response to a particular vowel contrast. Scores for the early bilingual listeners are represented by circles, whereas scores for late bilingual listeners are represented by triangles. As the figure shows, in general AE vowels that had a high assimilation overlap score yielded high discrimination errors. A Spearman rank order correlation indicated a strong correlation between overlap scores and discrimination errors ($\rho = .543$, $p = .266$) as shown in Appendix V. However, this correlation did not reach statistical significance as the sample size was small. When the control contrast was excluded, the findings were similar. Likewise, for late bilingual listeners, as the cross-language assimilation overlap increased, so did discrimination errors ($\rho = .829$, $p = .042$). This suggests that for late bilingual listeners, perceptual assimilation patterns were highly correlated with

discrimination performance. However, results should be interpreted with caution due to the small sample size.

Chapter 4. Discussion

4.1 Summary

This study evaluated the perception of American English vowels by native Spanish adults who were early or late learners of English, with the goals of understanding the perceptual patterns of this large population of bilinguals and relating the findings to general questions about perceptual changes that occur in second-language learning. To the author's knowledge, this is the first study that measures the effects of age of L2 acquisition in vowel perception in two commonly spoken languages (AE and Spanish) in natural speech and in the context of noise, which represents everyday conditions in which speech perception takes place.

In a Perceptual Assimilation task, early bilingual listeners demonstrated similar perceptual assimilation patterns to late bilingual listeners, but judged AE vowels as less Spanish sounding than did late learners. Early bilinguals also discriminated and identified AE vowels more accurately than did late bilingual listeners, although not as accurately as did native speakers. For both early and late bilingual listeners, some vowels (/ʌ/, /ɑ/ and /æ/) were more difficult to discriminate and identify than others. AE vowels in contrasts with speech sounds that were assimilated to separate native vowel categories in the Perceptual Assimilation task were discriminated more accurately than those contrasts whose vowels were assimilated to the same native vowel categories, an outcome predicted by the Perceptual Assimilation Model-L2 (Best & Tyler, 1997).

4.2. Perceptual assimilation results: language background

Although similar perceptual assimilation patterns were found between early and late bilingual listeners in the present study, the majority of AE vowels received higher median goodness ratings by late bilingual than early bilingual listeners, suggesting that late bilingual listeners accepted AE vowels as better instances of their Spanish categories. Thus, although similar perceptual assimilation patterns were present, early bilinguals may have become more attuned to the differences between AE and Spanish vowels than late bilingual listeners. This is consistent with Levy's (2009) finding that overall median goodness ratings for Parisian French vowels were higher for AE listeners with minimal French experience than for AE listeners with extensive French experience, suggesting that listeners perceived L2 vowels as less like their native vowels with increased French language experience. Therefore, learning to recognize phonetic differences between native and L2 vowels appears to come with early and extensive exposure to the L2.

4.2.1 Perceptual assimilation results: particular vowels

In the present study, perceptual assimilation patterns demonstrated by listeners indicate that certain AE vowels are more difficult for native Spanish speakers to categorize than others. For example, early and late bilingual listeners consistently assimilated AE front vowel /ɛ/ to a single native category (Spanish /e/), suggesting that AE /ɛ/ was perceived as a good exemplar of Spanish /e/. Conversely, early and late bilingual listeners at times assimilated AE vowels to more than one native category. For example, AE central vowel /ʌ/ was most often assimilated to Spanish back vowels (Spanish /u/ and /o/) and to a Spanish central vowel /a/. AE vowel /ʌ/ may have been

assimilated to Spanish /a/ due to their proximity in vowel space (AE vowel /ʌ/: F1 820 Hz, F2 1522 Hz; Spanish /a/: F1 638 Hz, F2 1353 Hz) (Bradlow, 1995). Surprisingly, AE vowel /ʌ/ was assimilated to Spanish /u/, perhaps influenced by orthography. Lastly, early and late bilingual listeners assimilated several AE vowels (AE back vowel /ɑ/ and AE front vowel /æ/) to a single native category (central Spanish vowel /a/). Although listeners assimilated an AE back vowel (AE /ɑ/) to a central Spanish vowel (Spanish /a/), the F2 value, indicating vowel backness, for AE vowel /ɑ/ (1463 Hz) was more similar to the F2 value of Spanish vowel /a/ (1353 Hz) (Bradlow, 1995) than to back Spanish vowels (Spanish /o/: 1019 Hz; Spanish /u/: 992 Hz) (Bradlow, 1995). AE front vowel /æ/ may have been assimilated to a central Spanish /a/ due to its similar F1 value, reflecting vowel height (AE vowel /æ/: 682 Hz, Spanish /a/ (638 Hz) (Bradlow, 1995). However, AE front vowel /æ/ had a more similar F2 value to Spanish /e/ (AE vowel /æ/: 1864 Hz, Spanish /e/: 1814 Hz) (Bradlow, 1995) than to Spanish /a/ (1353 Hz) (Bradlow, 1995). Despite the similar F2 values between AE /æ/ and Spanish /e/, listeners may have assimilated AE /æ/ to Spanish /a/ because Spanish /e/ was found to be a good exemplar of AE vowel /ɛ/. This suggests that listeners will not assimilate an L2 vowel to a native category that has already been established for another L2 vowel despite the similarity in vowel height or backness between that native and L2 vowel. Overall, perceptual assimilation patterns found in the present study are similar to patterns found in Morrison's (2008) perceptual assimilation study of Western Canadian-English synthetic vowels by monolingual Mexican-Spanish and monolingual Peninsular-Spanish listeners, Flege's (1991) identification study of AE vowels by late Spanish-English bilingual

listeners, as well as Escudero and Chládková's (2010) perceptual assimilation study of synthetic AE vowels by Peruvian Spanish monolingual listeners.

According to the Speech Learning Model (SLM) (Flege, 1995), L2 learners must detect phonetic differences between L2 and native sounds before establishing a new L2 category. That is, when AE vowels are accepted as good instances of Spanish categories, there will be little learning. However, when AE vowels are perceived as less like native vowels, evidence of learning will be observed. In the present study, AE /ɑ/ and /ʌ/ received higher median goodness rating than AE /ɪ/ /æ/, and /o/ suggesting that AE /ɪ/ /æ/, and /o/ may be easier to learn as they are perceived to be much different than Spanish vowels and that listeners presumably established new L2 categories for these vowels.

4.3. Categorial discrimination results: language background

In this study, discrimination accuracy increased as a function of early exposure to the L2, which is consistent with the cross-language speech perception literature (Flege et al., 1999; Flege & MacKay, 2004) and was predicted at the outset of the study, suggesting that early L2 acquisition heightens Spanish bilingual listeners' ability to perceive cross-language phonetic differences. The present study's finding that monolingual AE listeners discriminated AE vowels most accurately, followed by early bilingual and late bilingual listeners is in line with Flege and MacKay's (2004) and Flege et al.'s (1999) finding that early Italian-English bilingual listeners discriminated Canadian-English vowels more accurately than late Italian-English listeners. The significant language background and experience effect is also consistent with Levy's (2009) and Levy and Strange's (2008) finding that listeners who had studied French discriminated most French vowels more accurately than non-French-speaking AE

listeners. Furthermore, AE listeners with extensive French immersion experience discriminated Parisian French vowel contrasts more accurately than AE listeners with formal French experience (Levy, 2009a).

Although discrimination accuracy of L2 vowels improved with early age of L2 acquisition (mean age = 5 years), early bilingual listeners' vowel discrimination was not native-like, suggesting that early bilingual listeners' native vowel system may continue to influence their L2 vowel perception, despite their early age of second language acquisition. These findings are consistent with Pallier, Bosch, and Sebastian-Galles (1997), who found that early Spanish-Catalan bilingual listeners had difficulty discriminating Catalan vowel contrasts despite their early exposure to Catalan.

Individual differences among early bilingual listeners in the present study may have influenced their perceptual accuracy. For example, early bilinguals' daily use of Spanish varied among listeners (25% vs 75%). High-continued use of Spanish may have negatively impacted early bilingual listeners' performance, as Flege et al. (2004) found that early Italian-English bilingual listeners with "high-continued use" of their native language discriminated Canadian-English vowels less accurately than early Italian-English bilingual listeners with "low-continued use" of their native language. This suggests that high use of a native language may influence the phonetic properties of the native language despite listeners' early age of L2 acquisition. Additionally, in the present study, length of residence (LOR) varied among early bilingual listeners (10 vs 42 yrs). Previous studies have shown that LOR in the L2 country influences the accuracy of L2 vowel perception (Morrison, 2002; Flege, 1991; Flege et al., 1997), suggesting that listeners who reside in their L2 country for a longer period more accurately perceive L2

vowels than listeners with a shorter LOR. Additional studies with more participants are needed to control for factors confounding with age.

4.3.1. Categorial discrimination results: particular vowels

Discrimination accuracy varied as a function of the particular vowel contrast in this study, suggesting that the relationship between Spanish and AE vowel inventories causes some vowels to be more difficult to discriminate than others. Given that there are more AE than Spanish vowels, it is expected that Spanish bilingual listeners would discriminate AE vowels in a single category assimilation type pattern. The present study showed that single category type patterns (e.g. vowels in contrasts /ʌ-æ/, /ʌ-ɑ/, and /æ-ɑ/ were assimilated to Spanish /a/) are common for Spanish bilingual listeners, but listeners also discriminate AE vowels as separate phonetic categories (e.g. /ɑ-i/).

Overall, some contrasts were discriminated more accurately than others, indicating that certain contrasts were more learnable than others. When listeners assimilated AE vowels to a single native vowel, their discrimination accuracy was reduced. Higher discrimination accuracy was revealed when AE vowels were assimilated to distinct native vowels. For example, the control contrast /ɑ-i/, which contains vowels distant in vowel space, resulted in few discrimination errors. Although early and late bilingual listeners assimilated each AE vowel in contrast /ɪ-ɛ/ to Spanish /e/, listeners more often assimilated AE vowel /ɛ/ to Spanish /e/ than AE vowel /ɪ/ to Spanish /e/. Therefore AE vowel /ɛ/ may have been considered a "better instance" of Spanish /e/ than AE vowel /ɪ/ as suggested by the PAM-L2's (Best & Tyler, 2007) category-goodness assimilation type pattern yielding moderate to very good discrimination accuracy. Additionally, vowel contrast /ɪ-i/ was discriminated with high accuracy by listeners.

Despite the proximity of these vowels in vowel space, each AE vowel was assimilated to two different native vowels (Spanish /e/ and /i/), which resulted in few discrimination errors. This finding conflicts with previous studies that indicate poor discrimination accuracy for this vowel contrast (Escudero, 2000; Morrison, 2008; 2009). However, it should be noted that previous studies used different stimuli (Scottish, British, and Canadian English synthetic vowels) and participants (Spanish monolingual listeners).

Conversely, AE vowel contrasts that contained AE central vowel /ʌ/, such as /ʌ-æ/ and /ʌ-ɑ/ were discriminated with poor accuracy. This finding suggests that even early bilingual listeners who acquired English at an early age have difficulty discriminating these vowels. Listeners assimilated the vowels in each of these contrasts to a single native vowel (Spanish /a/). Vowel contrast /æ-ɑ/, containing two low vowels, was also discriminated poorly. These two vowels were also presumably assimilated in a single-category assimilation pattern. These findings support studies indicating that L2 vowels will be discriminated less accurately if both L2 vowels are assimilated to instances of a single native language vowel (Best & Tyler, 2007). Implications for learning these difficult L2 vowel contrasts can be explained in the framework of Second Language Linguistic Perception Model (L2LP) (Escudero, 2005). This model posits that L2 listeners who perceive each vowel in an L2 contrast as the same native category will either "split" their existing native category or create a new one. Spanish bilingual listeners may need to split their existing Spanish category /a/ to successfully discriminate /ʌ-æ/ and /ʌ-ɑ/ contrasts. That is, listeners may redefine their native categories to accurately discriminate difficult L2 vowels contrasts that may exist in a large L2 vowel inventory.

4.4. Identification results: language background

As predicted, monolingual AE listeners identified AE vowels with the highest accuracy, followed by early bilingual and late bilingual listeners. Thus, as predicted, early bilingual listeners have an advantage in identifying L2 vowels. However, early bilingual listeners did not identify AE vowels in a native-like manner, suggesting that the phonetic properties of their native language influenced L2 speech perception, consistent with previous studies (Mack, 1989). Therefore, although identification of L2 vowels improves with age of L2 acquisition, early bilingual listeners' native phonological knowledge may always be present and continue to influence L2 perception.

These findings provide support for the SLM (Flege, 1995), according to which early bilingual listeners are more likely than late bilingual listeners to form categories for L2 vowels. This could be attributed to the interaction hypothesis, which posits that early bilinguals' native vowel categories are developing and less likely to interact with their L2 at the time of L2 learning. Therefore early bilinguals' native and L2 vowels are less likely to influence each other than late bilinguals'. Additionally, the interaction hypothesis posits that early bilinguals' native categories are more malleable than those of late bilinguals and therefore early bilinguals are more likely to restructure their native phonetic system to accommodate L2 categories.

4.4.1. Identification results: particular vowels

Identification accuracy varied as a function of the particular vowel suggesting that the relationship between Spanish and AE vowel inventories can explain the difficulties that arise in identification of AE vowels by Spanish bilingual listeners. Performance on identification tasks can be explained by perceptual assimilation patterns

observed in the perceptual assimilation task. For example, AE vowel /i/ was identified most accurately by all groups which may be attributed to this vowel being consistently assimilated to one native category as observed in the perceptual assimilation tasks. AE vowels /ɪ/ and /ɛ/ were identified with moderate accuracy by early and late bilinguals which may have resulted from these vowels being assimilated to the same native category (Spanish /e/). AE central vowel /ʌ/ was identified with poor accuracy by early and late bilingual listeners, which may be explained by observations from the Perceptual Assimilation task, as this vowel was assimilated to multiple Spanish vowels (/u/, /a/, and /o/). Listeners may not have formed a clear category for this vowel, yielding poor identification accuracy. AE vowel /ɑ/ was incorrectly identified as AE vowel /æ/, which may be a result of confusion with the orthographic representation of AE vowel /æ/ in the selected key word response "gabappa" and Spanish /a/ in "gaboppa", the vowel that was most assimilated to AE vowel /ɑ/. Additionally, the incorrect identification of AE control vowel /o/ may be attributed to the orthographic representation of AE vowel /o/ in the keyword response "gaboapa" and the selected keyword "gaboppa" (AE vowel /ɑ/) by early and late bilingual listeners. Future studies may take into consideration these orthographic confusions in keyword responses.

Overall, findings suggest that AE mid (/ʌ/) and low (/æ/, /ɑ/) vowels are difficult for Spanish bilingual listeners to identify, which can be explained by the difference in mid and low vowel inventory size between Spanish and AE (AE: 6 mid vowels, 2 low vowels; Spanish: 2 mid vowels, 1 low vowel). Therefore, Spanish listeners have fewer native vowel categories to assimilate AE low and mid vowels, resulting in difficulty in identifying AE /ʌ/, /æ/, and /ɑ/ according to the PAM-L2.

4.5. Predicting discrimination performance from perceptual assimilation patterns

By examining the relationship between native and L2 vowels through the framework of the PAM-L2 (Best & Tyler, 2007), predictions can be made about the difficulty that Spanish listeners will have when discriminating certain AE vowel contrasts. According to the PAM-L2, listeners' perceptual assimilation patterns predict discrimination outcomes. In the present study, the PAM-L2 predicted the discrimination of AE vowels based on the perceived relationship between AE and Spanish vowels. Previous cross-language speech perception studies have tested predictions proposed by the PAM-L2 with naïve learners. For example, Fabra and Romero (2012) found that Catalan learners varying in English proficiency demonstrated poor discrimination when AE vowels were assimilated in a single category assimilation type pattern and good discrimination when vowels were assimilated in a category goodness assimilation type pattern. Similarly, Levy (2009) found that Parisian French vowels that were assimilated in a single assimilation pattern by AE listeners differing in French experience were more difficult to differentiate than Parisian French vowels that were assimilated in a two category assimilation pattern. Findings from the present study support predictions made by the PAM-L2 with listeners in more advanced stages of L2 learning (early and late bilinguals) than listeners in previous studies.

As predicted, in the present study, vowel contrasts whose segments were assimilated to separate vowel categories were discriminated with excellent accuracy, consistent with the PAM-L2. For example, segments in vowel contrast /i-ɑ/ were assimilated in a two-category assimilation type pattern and were discriminated with high accuracy. Vowel contrasts such as /ɪ-ɛ/ whose segments were assimilated to the same

native category (AE /ɪ/ and /ɛ/ to Spanish /e/), but one segment was considered more similar to the Spanish /e/ than the other (category-goodness assimilation type pattern) yielded moderate to very good discrimination accuracy. According to PAM-L2, it is likely that a new speech sound category was formed for the less similar L2 segment (AE /ɪ/) during L2 development. When both AE vowels in a contrast were assimilated to a single native category, discrimination accuracy was poor. For example, AE vowels /ʌ/ and /æ/ were perceptually assimilated to Spanish /a/ and, as expected, these vowels were poorly discriminated.

4.6. Limitations

It is important to note the methodological limitations of this study. For example, the stimuli were spoken by only three native AE speakers who were all from the New York regional area for consistency of dialect. Previous studies have shown that the dialect of the non-native language may have an effect on the way vowels are perceived by non-native listeners (Escudero & Chládková, 2010). Thus results obtained from listeners' responses may not be generalizable.

Another limitation of the study was the complexity of the listeners' language background. Listeners in this study came from diverse language backgrounds with a range of continued use of the native language and length of residence (LOR) in the L2 country. These factors have been found to affect accuracy of L2 speech perception (Flege, 1991; Flege, Bohn, & Jang, 1997; Flege & MacKay, 2004; Levy, 2009; Levy & Strange, 2008; Morrison, 2002). Additionally, listeners came from diverse dialectal backgrounds, even though all were native Spanish speakers. Previous studies have shown that, in addition to the dialect of the L2 language, the dialect of the native

language may result in differences in L2 vowel perception (Morrison, 2008). An analysis grouping the listeners by continued use of the native language, LOR, and dialect may reveal perceptual differences in listeners. Future studies with more participants could allow subgroup comparisons without loss of statistical power.

4.7. Conclusion and future directions

Findings from the present study support the numerous studies indicating that L2 vowel perception is affected by the age of L2 acquisition and differences in native and L2 vowel inventories. It further provides information about the perception of AE vowels by early and late Spanish-English bilinguals in natural speech and everyday conditions (in the presence of noise). The earlier age of L2 acquisition was associated with fewer discrimination and identification errors. However, early bilinguals did not demonstrate native-like perception of AE vowels.

In this study, certain AE vowels were challenging to discriminate and identify for bilingual listeners. Especially with the increasing numbers of Hispanic immigrants that are entering the US (US Census Bureau, 2011) and are learning AE as a second language, this information is valuable for those professionals working with this population. Perceptual training programs to improve bilinguals' perception of these challenging AE vowels can be developed during the early years of L2 acquisition, as findings indicate that the timing of L2 acquisition influences perception of the L2. Additionally, future studies may investigate the correlation between the perception and production of L2 vowels in order to gain information about the relationship between bilingual listeners' perception and their production of L2 vowels and the extent that perceptually difficult AE vowels are affected in production.

An extension of this study to typically developing children's vowel perception would be useful in documenting changes in children's L2 perception. Additionally, a study of L2 vowel perception in phonologically impaired Spanish-English bilingual children may provide information about perceptual learning in individuals who may have difficulty perceiving speech sounds in their native language and are faced with a new system of phonetic categories.

5. Tables

Table 1.

Perceptual assimilation patterns of American English (AE) vowels to Spanish vowels by early bilingual listeners. Percent chosen for the Spanish vowel responses selected are presented for each AE vowel stimulus.

AE Vowel Stimulus	Spanish Vowel Response				
	/a/	/e/	/i/	/o/	/u/
/i/	0	4.1	95	0.4	0.2
/ɪ/	0.6	49	50	0.2	0.7
/ɛ/	4.6	94	0.7	0.2	0.9
/æ/	92	7	0.2	0.9	0.2
/ɑ/	83	0.4	0	11	6
/ʌ/	30	4.3	0.2	24	42
/o/	0.9	0	0	96	3

Table 2.

Perceptual assimilation patterns of American English (AE) vowels to Spanish vowels by late bilingual listeners. Percent chosen for the Spanish vowel responses selected are presented for each AE vowel stimulus.

AE Vowel Stimulus	Spanish Vowel Response				
	/a/	/e/	/i/	/o/	/u/
/i/	0.2	3.3	96	0	0.2
/ɪ/	0.2	49	50	0.9	0
/ɛ/	11.3	87	0.6	1.5	0
/æ/	82	14	0.6	4	0.4
/ɑ/	75	1.3	0.2	23	0.7
/ʌ/	53	6.7	0.7	39	0.9
/o/	0.3	1.5	0	98	0.3

Table 3.

Perceptual assimilation of AE vowels by early and late Spanish bilingual listeners: Percent chosen for each modal response (most frequent category chosen) and median goodness ratings (scale from 1-9, with (1) indicating "least Spanish-like" and (9) indicating "most Spanish-like") are presented for each vowel.

Early Bilingual Listeners			
AE stimulus	Spanish modal choice	Mode percent chosen	Median Rating
/i/	/i/	95	5
/ɪ/	/i/	50	6
/ɛ/	/e/	94	1
/æ/	/a/	92	3
/ɑ/	/a/	83	7
/ʌ/	/u/	42	7
/o/	/o/	96	6

Late Bilingual Listeners			
AE stimulus	Spanish modal choice	Mode percent chosen	Median Rating
/i/	/i/	96	5
/ɪ/	/i/	50	8
/ɛ/	/e/	87	5
/æ/	/a/	82	8
/ɑ/	/a/	75	9
/ʌ/	/a/	53	8
/o/	/o/	98	9

Table 4.

Discrimination accuracy and cross-language assimilation overlap by listener group and vowel contrast. A cross-language assimilation overlap score and a categorial discrimination percent error score for each bilingual group are presented.

Vowel Contrast	N	Cross-language Assimilation Overlap (%)	Categorial Discrimination Percent Errors (%)
Early Bilingual Listeners			
/i-ɑ/	12	0.9	2.4
/ʌ-æ/	12	32.4	22.7
/ʌ-ɑ/	12	42	26.9
/ɪ-ɛ/	12	48.3	9.4
/ɪ-i/	12	51.3	14.2
/æ-ɑ/	12	79.8	28.5
Late Bilingual Listeners			
/i-ɑ/	12	.73	3.1
/ɪ-ɛ/	12	49.1	22
/ɪ-i/	12	52.8	26
/ʌ-æ/	12	60.8	42.6
/æ-ɑ/	12	75.9	40.1
/ʌ-ɑ/	12	76.1	41

6. Figures

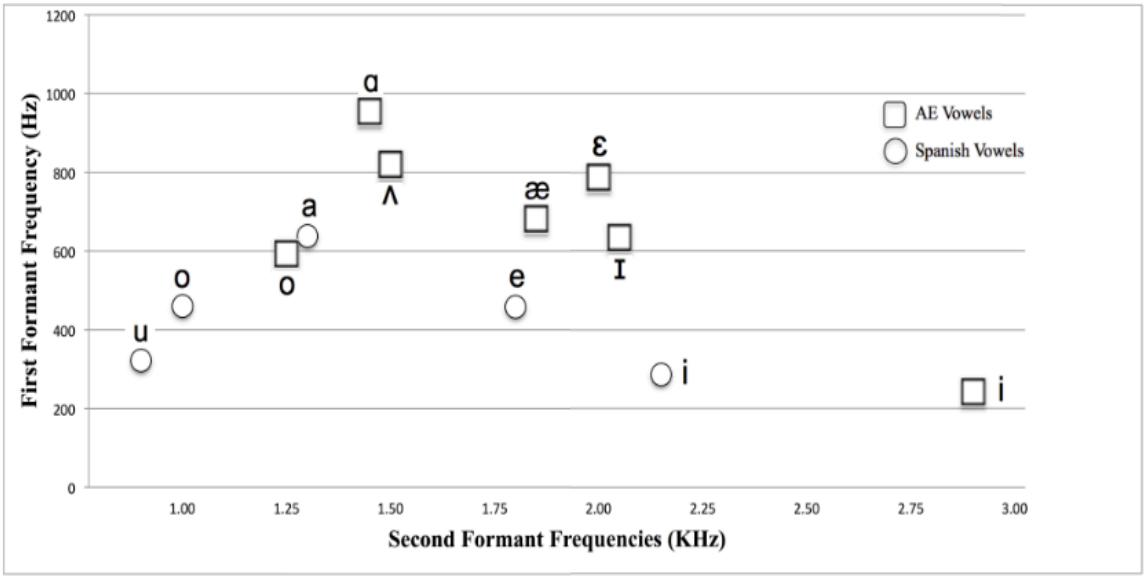


Figure 1. Mean Formant 1/Formant 2 vowel spaces (in Hertz) of American English (AE) vowels are represented by squares: averages of 3 tokens from 3 monolingual female speakers of AE English in /gəbVpə/ context in the phrase "five /gəbVpə/ this time". Mean F1/F2 vowel spaces (in Hertz) of Castilian Spanish vowel tokens taken from Bradlow's (1995) cross-linguistic study of AE and Castilian Spanish vowels are represented by circles.

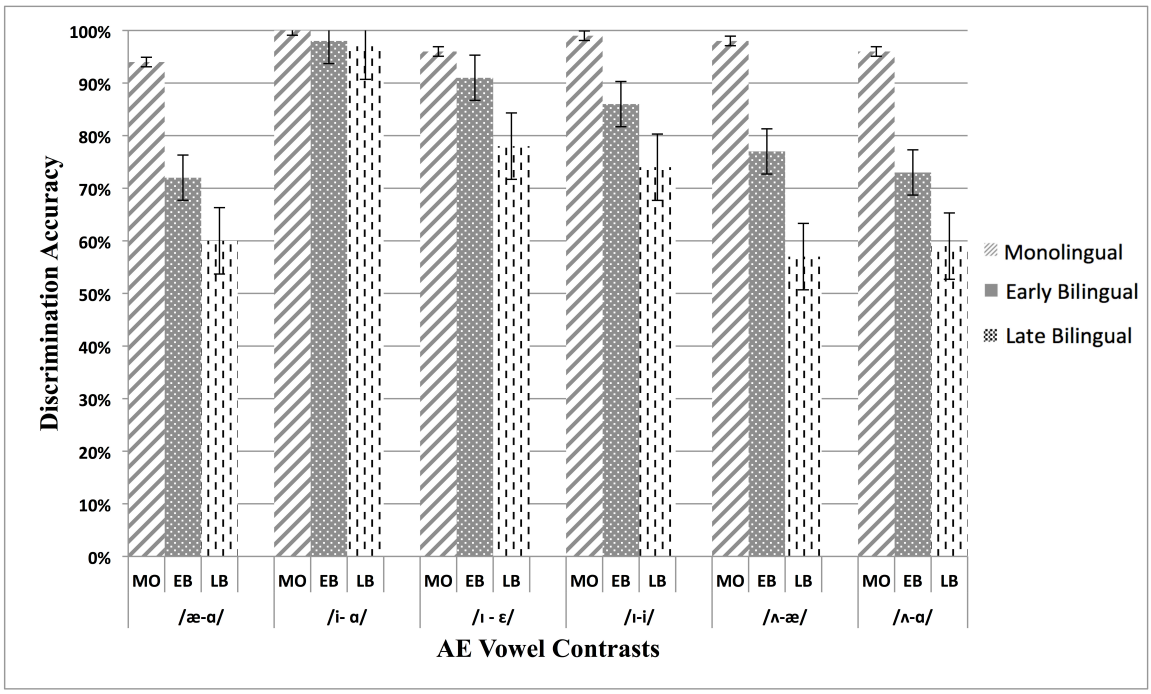


Figure 2. Mean discrimination accuracy of American English (AE) vowel contrasts by monolingual AE listeners (MO) and Early (EB) and Late Bilingual (LB) Listeners. Percent correct and standard error of the mean are given.

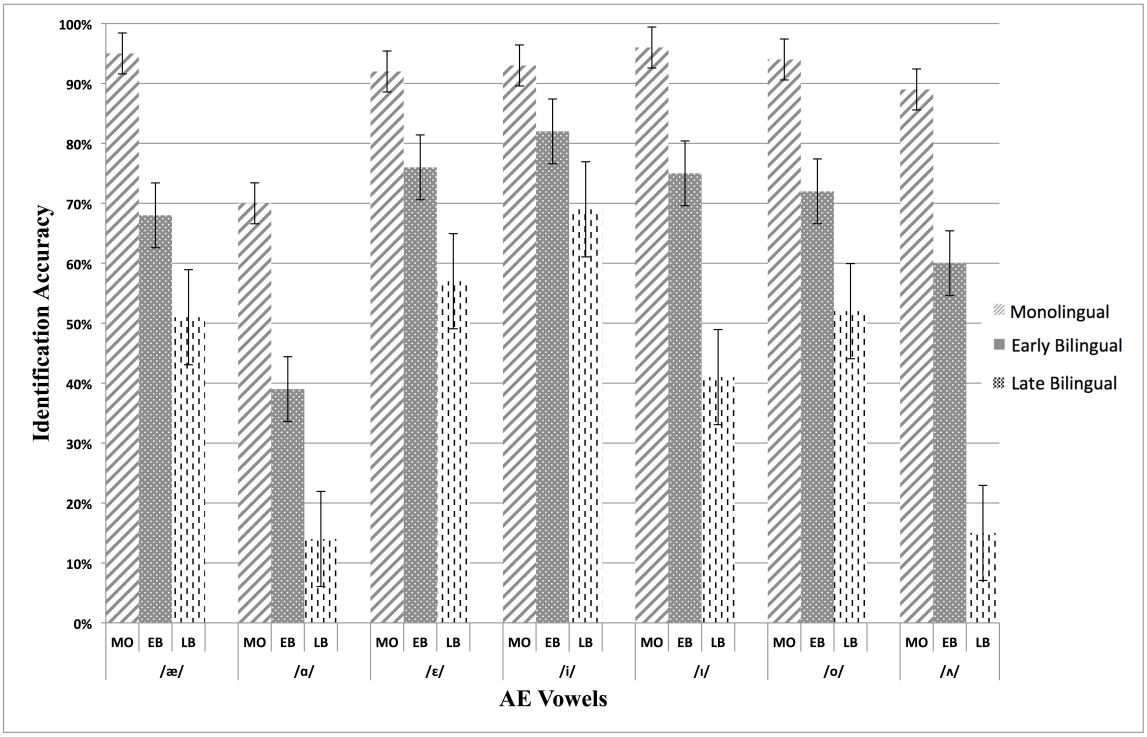


Figure 3. Mean identification accuracy of AE vowels by monolingual AE listeners (MO) and early (EB) and late bilingual (LB) listeners. Percent correct and standard error of the mean are given.

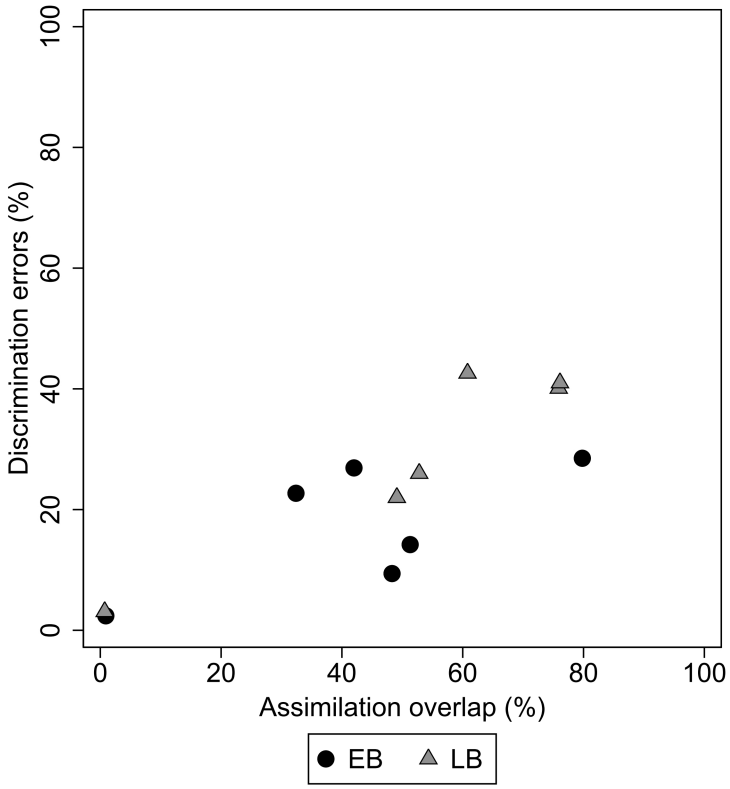


Figure 4. Scatter plot of relation between percent overlap in perceptual assimilation patterns and percent errors in categorial discrimination by early and late bilingual listeners.

5. References

Adachi, T., Akahane- Yamada, R., & Ueda, K. (2006). Intelligibility of English phonemes in noise for native and non-native listeners. *Acoustical Science and Technology, 27,* 285-289.

Best, C. T. (1995). A direct realist view of cross-language speech perception. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Best, C.T. & Tyler, M.D. (2007). Nonnative and second-language speech perception. In O-S. Bohn & M.J. Munro (Eds.), *Language experience in second language speech learning: in honor of James Emil Flege*. Philadelphia: John Benjamins Publishing Company.

Bilger, R.C., Nuetzel, J.M., Rabinowitz, W.M., & Rzeczkowski, C. (1984). Standardization of a test of speech perception in noise. *Journal of Speech and Hearing Research, 27,* 32-38.

Bradlow, A. R. (1995). A comparative acoustic study of English and Spanish vowels. *Journal of the Acoustical Society of America, 97,* 1916–1924.

Broersma, M. & Scharenberg, O. (2010). Native and non-native listeners' perception of English consonants in different types of noise. *Speech Communication, 52,* 980–995.

Escudero, P. (2005). "Linguistic perception and second-language acquisition: explaining the attainment of optimal phonological categorization," PhD thesis, Utrecht University, The Netherlands.

Escudero, P. & Boersma, P. (2004). Bridging the gap between L2 speech perception research and phonological theory. *Studies in Second Language Acquisition, 26,* 551 – 585.

Escudero, P. & Chládková, K. (2010). Spanish listeners' perception of American and Southern British English vowels. *Journal of the Acoustical Society of America, 128,* EL254-EL 260.

Ferguson, S. H. (2012). Talker differences in clear and conversational speech: Vowel intelligibility for older adults with hearing losss. *Journal of Speech, Language, and Hearing Research, 55*, 779-790.

Fabra & Romero (2012). Native Catalan learners' perception and production of English vowels. *Journal of Phonetics, 40*, 491–508.

Flege, J.E. (1991). The interlingual identification of Spanish and English vowels: orthographic evidence. *The Quarterly Journal of Experimental Psychology, 43A*, 701-731.

Flege, J. E. (1995). Second language speech learning: Theory, findings, and problems. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Flege, J.E. (1997). Effects of experience on non-native speakers' production and perception of English vowels. *Journal of Phonetics, 25,* 437-470.

Flege, J.E., Bohn, O-S., & Jang, S. (1997). Effects of experience on non-native speakers' production and perception of English vowels. *Journal of Phonetics, 25,* 437-470.

Flege, J.E. & MacKay, I.R.A. (2004). Perceiving vowels in a second language. *Studies in Second Language Acquisition, 26,* 1-34.

Flege, J.E., MacKay, I.R.A., & Meador (1999). Native Italian speakers' perception and production of English vowels. *Journal of the Acoustical Society of America, 106,* 2973- 2987.

Flege, J.E., Munro, M.J., & Fox, R.A. (1994). Auditory and categorical effects on cross-language vowel perception. *Journal of the Acoustical Society of America, 95,* 3623-3641.

Flege, J.E., Schirru, C., & MacKay, I.R.A. (2003). Interaction between the native and second language phonetic subsystems. *Speech Communication, 40,* 467-491.

Fox, R.A., Flege, J.E., & Munro, M.J. (1995). The perception of English and Spanish vowels by native English and Spanish listeners: A multidimensional scaling analysis. *Journal of the Acoustical Society of America, 97,* 2540-2551.

Garcia Lecumberri, M.L., Cooke, M., & Cutler, A. (2010). Non-native speech perception in adverse conditions: A review. *Speech Communication,* 864-886.

Gottfried, T. L. (1984). Effects of consonant context on the perception of French vowels. *Journal of Phonetics, 12*, 91-114.

Humes, R., Jones, A., & Ramirez, R.R. (2011). "Overview of Race and Hispanic Origin: 2010". U.S. Census Bureau.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*, 434-446.

Kalikow, D.N., Stevens, K.N., & Elliott, L.L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *Journal of the Acoustical Society of America, 61,* 1337-1351.

Kangas, K.A. & Allen, G.D. (1990). Intelligibility of synthetic speech for normal-hearing and hearing-impaired listeners. *Journal of Speech and Hearing Disorders, 55*, 751-755.

Kewley-Port, D., Burkle, T.Z. & Lee, J.H. (2007). Contribution of consonant versus vowel information to sentence intelligibility for young normal-hearing and elderly hearing-impaired listeners. *Journal of the Acoustical Society of America, 122*, 2365-2375.

Levy, E.S. (2009a). Language experience and consonantal context effects on perceptual assimilation of French vowels by American-English learners of French. *Journal of the Acoustical Society of America, 125*, 1138-1152.

Levy, E. S. (2009b). On the assimilation-discrimination relationship in American English adults' French vowel learning. *Journal of the Acoustical Society of America*, 126, 2670-2682.

Levy, E.S. & Strange, W. (2008). Perception of French vowels by American English adults with and without French language experience. *Journal of Phonetics, 36*, 141-157.

Mack, M. (1989). Consonant and vowel perception and production: early English-French bilinguals and English monolinguals. *Perception and Psychophysics, 46,* 186-200.

Mayo, L.H., Florentine, M., & Buus, S. (1997). Age of second-language acquisition and perception of speech in noise. *Journal of Speech, Language, and Hearing Research, 40,* 686-693.

Morrison, G.S. (2002). Perception of English /i/ and /ɪ/ by Japanese and Spanish listeners: longitudinal results. In G.S. Morrison, & L. Zsoldos (Eds.), *Proceedings of North West Linguistics Conference 2002,* pp. 29-48.

Morrison, G.S. (2008). Perception of synthetic vowels by monolingual Canadian-English, Mexican-Spanish, and Peninsular-Spanish listeners. *Canadian Acoustics, 36*, 17-23.

Neuman, A. & Hochberg, I. (1983). Children's perception of speech in reverberation. *Journal of the Acoustical Society of America*, *73*, 2145-2149.

Pallier, Bosch, & Sebastian-Galles (1997). A limit on behavioral plasticity in speech perception. *Cognition*, 64, B9-B17.

Piske, T., Flege, J.E., MacKay, I.R.A., & Meador, D. (2002). The production of English vowels by fluent early and late Italian-English bilinguals. *Phonetica*, *59*, 49–71.

Polka, L. & Werker, J.F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 421-435.

Shi, L.-F. (2010). Perception of acoustically degraded sentences in bilingual listeners who differ in age of English acquisition. *Journal of Speech, Language, and Hearing Research*, *53*, 821–835.

Strange, W., Weber, A., Levy, E., Shafiro, V., Hisagi, M., & Nishi, K. (2007). Acoustic variability within and across German, French, and American English vowels: Phonetic context effects. *Journal of the Acoustical Society of America, 122*, 1111-1129.

Ueda, K., Akahane- Yamada, R., & Komaki, R. (2002). Identification of English /r/ and /l/ in white noise by native and non-native listeners. *Acoustical Science and Technology, 23,* 336-338.

Von Hapsburg, D., Champlin, C.A., & Shetty, S.R. (2004). Reception thresholds for sentences in bilingual (Spanish/English) and monolingual (English) listeners. *Journal of the American Academy of Audiology, 15,* 88-98.

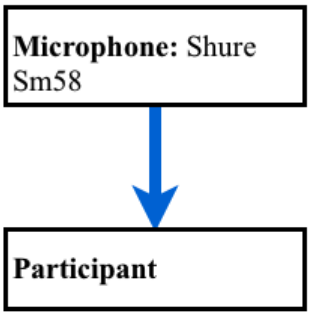
Appendices

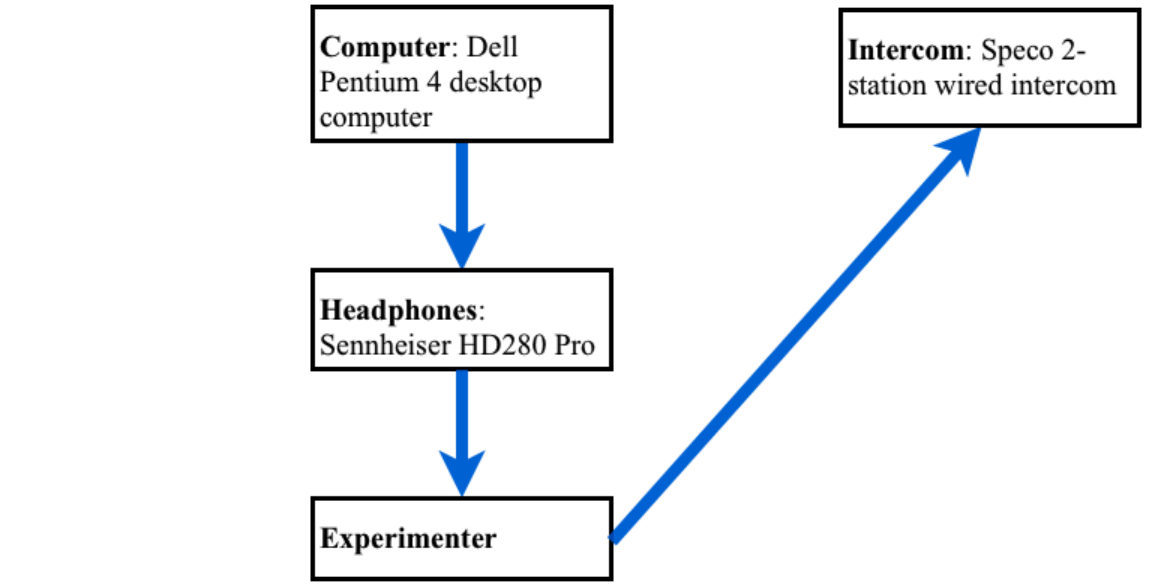
Appendix A: Protocol for Talkers

Order _____

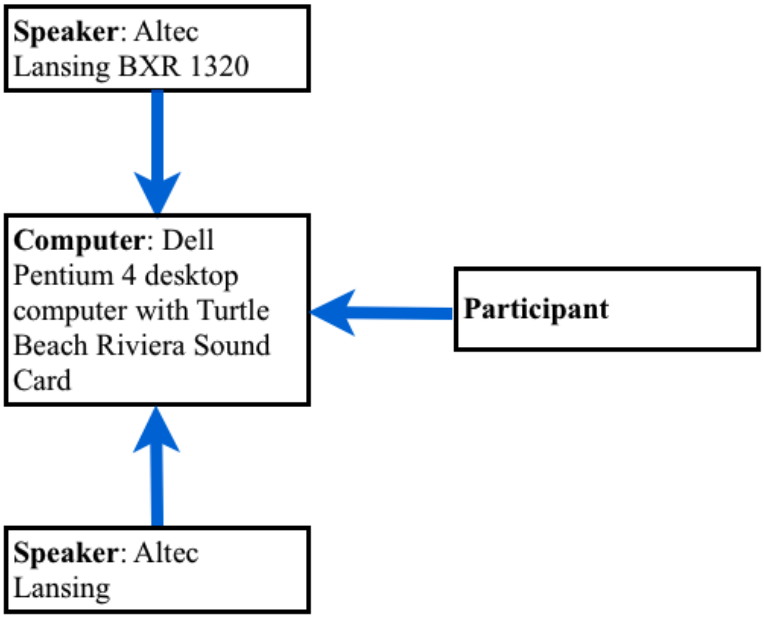
1. Five gabeepa this time.
8. Five gabuppa this time.
4. Five gabeppa this time.
5. Five gabappa this time. (hat)
2. Five gabippa this time.
3. Five gabaypa this time.
11. Five gaboopa this time.
9. Five gaboapa this time. (road)
6. Five gaboppa this time.
1. Five gabeepa this time.

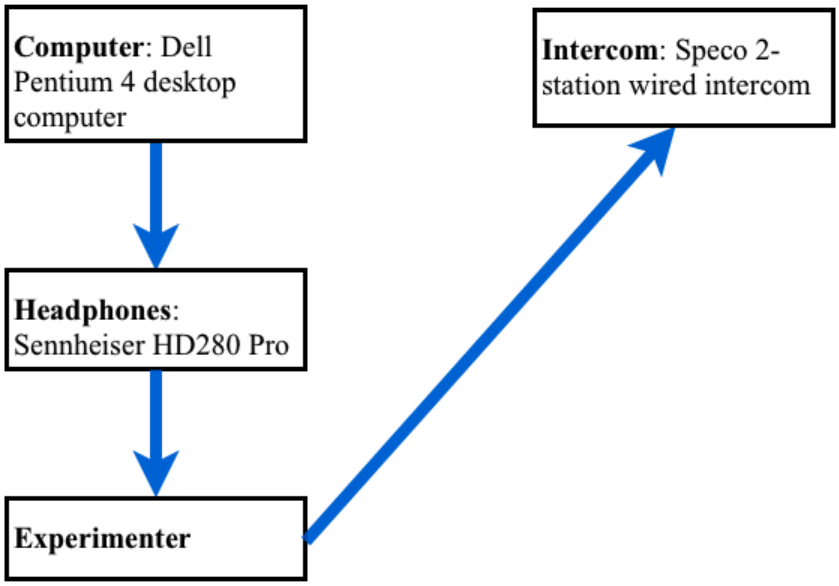
Appendix B: Flowchart of Recording Equipment





Appendix C: Flowchart of Equipment for Perceptual Tasks





Appendix D: Design of the Perceptual Assimilation Task

Task Familiarization:

1 block of /o/, /e/, and /u/ in a /gəbVpə/ context ; 10-trial task familiarization block.

Stimulus familiarization:

1 trial of each vowel from test block, totaling 6 trials.

Experiment:

1. 6 blocks
2. 6 AE vowels /(i/, /ɪ/, /ɛ/, /ʌ/, /æ /, and /ɑ/) x 3 talkers x 3 tokens of each word x 5 trials of each token, totaling 270 trials
3. Control /o/- 3 talkers x 3 tokens x 3 repetitions, totaling 27 trials
4. Total stimuli: 270 experimental trials + 27 control trials = 297 trials

Sequence of blocks:

Task familiarization: 10 trials

Stimulus familiarization: 6 trials

Experimental block 1: 50 trials

Experimental block 2: 50 trials

Experimental block 3: 50 trials

Experimental block 4: 50 trials

Experimental block 5: 50 trials

Experimental block 6: 47 trials

Appendix E: Instructions for Perceptual Assimilation Task

Familiarization

In this part of the experiment you will continue to hear the same nonsense words. Please listen to the second vowel sound of the word (e.g. gabeepa) and determine which Spanish sound is the best example of that sound. Indicate the vowel by choosing one of the following Spanish nonsense words:

bapo

bepo

bipo

bopo

bupo

Before we start, please read each of the above words aloud to the experimenter, and pronounce the vowel sound in each word by saying "bapo" has the vowel sound… "bepo" has the sound…

After you indicate the vowel, the same phrase will be presented again and you will see a rating scale from 1-9. The purpose of the scale is for you to indicate how good an example you feel the American English vowel is of the Spanish vowel you chose. If you feel the AE vowel is a good example of the Spanish vowel, choose a point on the scale near "most Spanish-like (9)." If you feel the AE vowel is a poor example of the Spanish vowel select a point near the "least Spanish-like" end of the scale (1).

So first listen to the second vowel of the American English nonsense word in the phrase and choose the Spanish key word that has the vowel that is the best example of that sound. Then listen to it a second time and rate how good an example it is.

You will now complete a practice block of 6 trials. In these trials you are going to hear the vowels that you will hear again in the experiment. This is just for practice so that you can get used to the vowels.

Do you have any questions?

When you're ready to begin, go ahead and click the left mouse button.

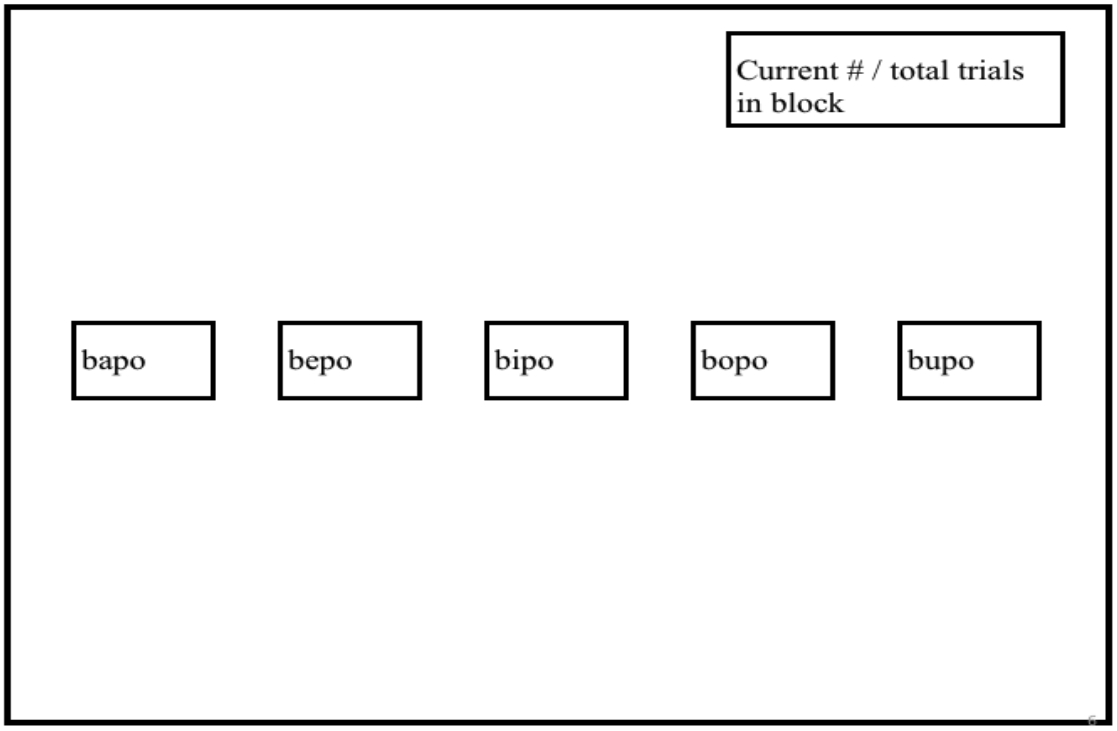
Experiment

You will now complete 6 blocks of about 50 trials. Again, first listen to the second vowel of the American English nonsense word in the phrase and choose the Spanish keyword that is a good example of that sound. Then rate the vowel. Please try to use the whole rating scale from 1-9. That is, do not just rate the vowels as most Spanish-like or least Spanish-like, but rather make detailed judgments about how good of an example or poor of an example the sounds are (use the numbers 2 through 8, too).

Do you have any questions?

When you're ready to begin, go ahead and click the left mouse.

Appendix F: Diagram of Computer Screen for Perceptual Assimilation Task



Appendix G: Design of the Categorial Discrimination Task

Task familiarization:

1 block of 3 contrasts (/ʌ-i/, /u-æ/, and /i-o/) in a /gəbVpə/ context in a carrier phrase "five gəpVpə this time" in an AXB paradigm; 3 talkers x 5 tokens of each vowel contrast, totaling 15 trials.

Stimulus familiarization:

1 copy of a test block; 22-trial stimulus familiarization block

Experiment:

1. 4 blocks
2. 5 vowel contrasts (/i- ɪ/, /ɪ-ɛ/, /ʌ-ɑ/, /ʌ-æ/, /æ -ɑ/) x 3 talkers x 3 tokens x 4 repetitions, totaling 180 responses
3. Control contrast /ɑ-i/ : 3 talkers x tokens x repetitions, totaling 24 trials
4. Total stimuli: 180 experimental trials + 24 control trials= 204 trials

Sequence of blocks:

Task familiarization: 15 trials

Stimulus Familiarization: 22 trials

Experimental block 1: 50 trials

Experimental block 2: 50 trials

Experimental block 3: 50 trials

Experimental block 4: 54 trials

Appendix H: Instructions for Categorial Discrimination Task

Familiarization

This experiment is about the way you hear speech sounds. Let's go over the vowels of American English using nonsense words in the form “gab-vowel-pa.” Please read each of the following words aloud to the experimenter:

gabeepa

gabippa

gabuppa

gabaypa

gaboapa (road)

gabeppa

gabappa (hat)

gaboopa

gaboppa

You will hear three phrases, such as "five gabeepa this time/ five gaboapa this time/ five gaboapa this time." The phrases will be spoken by three different people. The phrases will be in noise and may be hard to hear. Try to focus only on the pronunciation of the target vowel and ignore any other factors (e.g., recording, quality, rate, volume).

Your task is to say whether the vowel in the nonsense (target) word of the middle phrase is the same as the one in the first phrase or the one in the third phrase. For this example, the vowel in "gaboapa" in the middle phrase is the same as the vowel in the third phrase "gaboapa."

You will see the numbers "1" and "3" and an "X" on your screen. If the vowel in the target word of the middle phrase is the same as the one in the first phrase, click on "1". If, on the other hand, it is the same as the one in the third phrase, click on "3". In the example, you would click on "3" because the vowel in "gaboapa" in the middle sentence is the same as the vowel in "gaboapa" in the third phrase.

This first part of the study will be a practice section so that you become familiar with the task. You will hear 15 trials (sets of sentences). Do you have any questions? Please left click on the mouse when you're ready to continue.

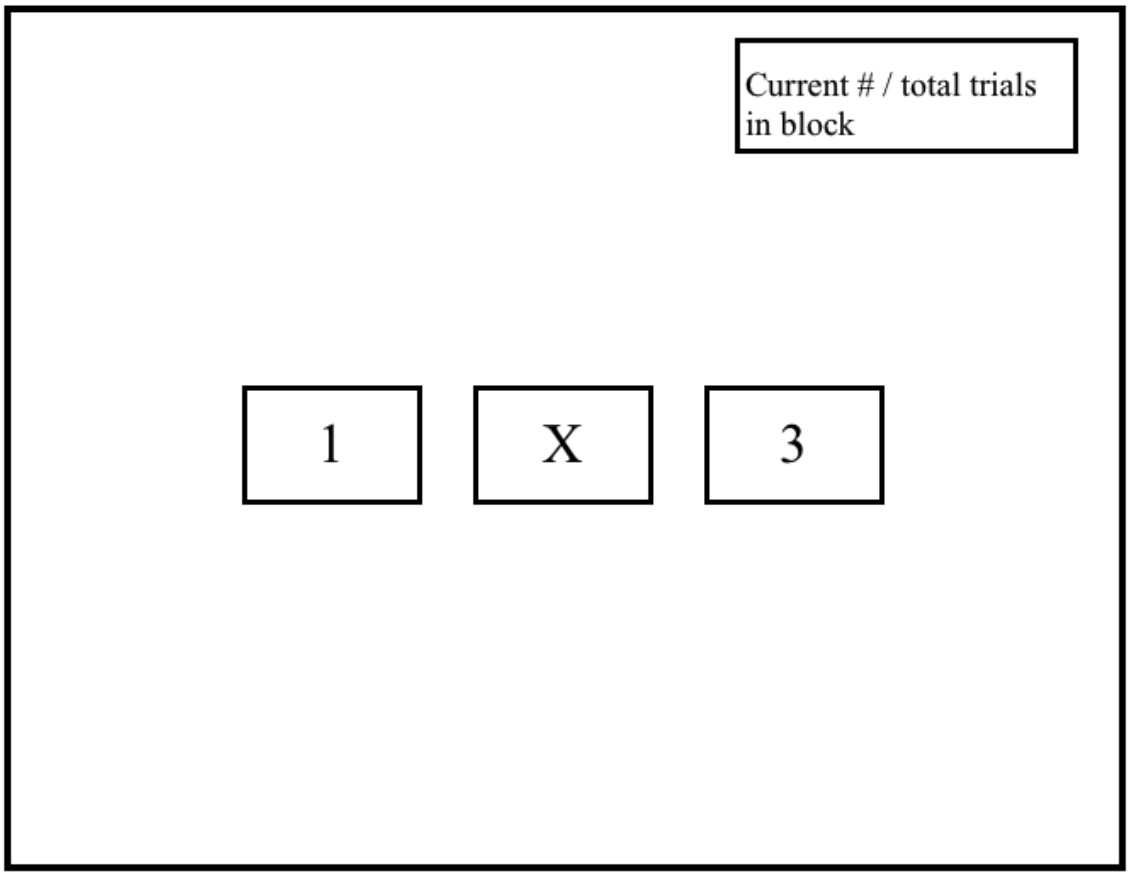
You will now complete another block of trials. This block is also a practice block so that you can become familiar with the words. It will have 22 trials. Do you have any questions? Remember your options are "1" or "3".

Experiment

You will now complete 4 blocks of about 50 trials. Remember your options are "1" or "3". Do you have any questions?

Whenever you're ready, press the left mouse button.

Appendix I: Diagram of Computer Screen for Categorial Discrimination Task



Appendix J: Design of the Identification Task

Task Familiarization:

1 block of /o/, /e/, and /u/ in a /gəbVpə/ context ; 10-trial task familiarization block.

Experiment:

1. 6 blocks
2. 6 AE vowels /(i/, /ɪ/, /ɛ/, /ʌ/, /æ /, and /ɑ/) x 3 talkers x 3 tokens of each word x 5 trials of each token, totaling 270 trials
3. Control /o/- 3 talkers x 3 tokens x 3 repetitions, totaling 27 trials
4. Total stimuli: 270 experimental trials + 27 control trials = 297 trials

Sequence of blocks:

Task familiarization: 10 trials

Experimental block 1: 50 trials

Experimental block 2: 50 trials

Experimental block 3: 50 trials

Experimental block 4: 50 trials

Experimental block 5: 50 trials

Experimental block 6: 47 trials

Appendix K: Instructions for Identification Task

Familiarization and Experiment:

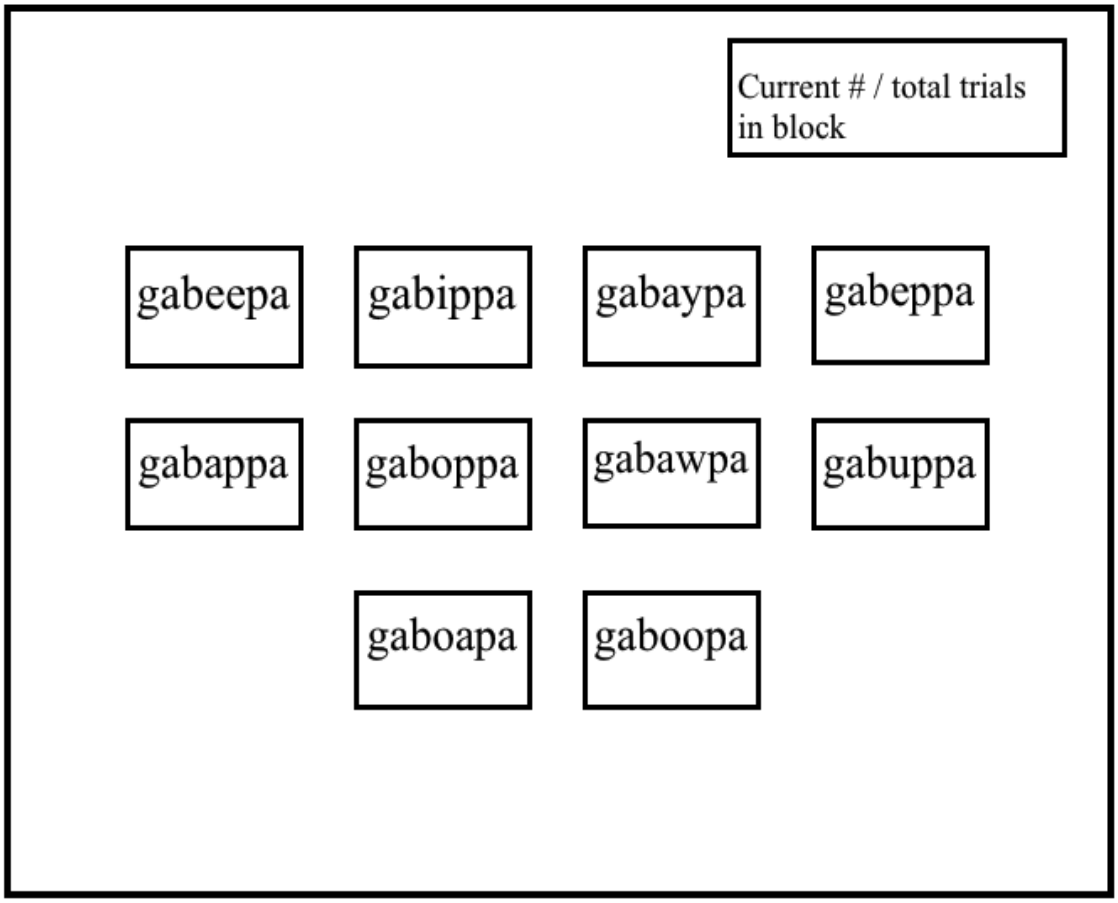
Now you will again hear people saying nonsense words in the form of "gab-vowel-pa" in phrases. The phrases will be in noise and may be hard to hear. You will then see the American English nonsense words you know (e.g., gabeepa, gabippa, etc.). When you hear the nonsense word, listen to the second vowel and choose the vowel you heard.

So you'll listen to the second vowel of the nonsense word ("gab-vowel-pa") in a phrase and choose the word that has the vowel you heard. Try to focus only on the pronunciation of the target vowel and ignore any other factors (e.g. recording, quality, rate, volume).

You will complete 7 blocks of phrases. The first block has 10 trials and the rest have approximately 50 trials. Do you have any questions?

Whenever you're ready, press the left mouse button. Thank you so much for your participation in this study. Please wait for the experimenter.

Appendix L: Diagram of Computer Screen for Identification Task



Appendix M: IRB Approval Letter

TEACHERS COLLEGE
COLUMBIA UNIVERSITY
OFFICE OF SPONSORED PROGRAMS

Institutional Review Board

May 7, 2014

Miriam Baigorri
41-36 72 Street
Woodside, NY 11377

Dear Miriam,

Thank you for submitting your study entitled, "*Early and Late Spanish-English Bilingual Adults' Perception of American English Vowels;*" the IRB has determined that your study is **Exempt** from committee review [Category **2**].

Please keep in mind that the IRB Committee must be contacted if there are any changes to your research protocol. The number assigned to your protocol is **14-251**. Feel free to contact the IRB Office [212-678-4105 or hersch@tc.edu] if you have any questions.

Please note that your consent form bears an official IRB authorization stamp. Copies of this form with the IRB stamp must be used for your research work.

Best wishes for your research work.

Sincerely,

Karen Froud, Ph.D.
Associate Professor of Speech and Language Pathology
Chair, IRB

cc: File, OSP

Appendix N: Participant Characteristics

Participant	Group	Age	Gender	Age of arrival to the US	Years of exposure to AE	English Use
101	MO	25	F	n/a	n/a	n/a
102	MO	24	F	n/a	n/a	n/a
103	MO	25	F	n/a	n/a	n/a
104	MO	27	F	n/a	n/a	n/a
105	MO	24	F	n/a	n/a	n/a
106	MO	24	F	n/a	n/a	n/a
107	MO	23	F	n/a	n/a	n/a
108	MO	33	F	n/a	n/a	n/a
109	MO	25	F	n/a	n/a	n/a
110	MO	32	F	n/a	n/a	n/a
201	EB	30	F	6	24	80%
202	EB	25	F	3	22	85%
203	EB	18	F	8	10	25%
204	EB	23	F	8	15	30%
205	EB	20	F	10	10	30%
206	EB	19	F	9	10	70%
207	EB	48	F	6	42	50%
208	EB	20	F	2	15	40%
209	EB	24	F	10	14	50%
210	EB	25	F	2	22	80%
211	EB	24	F	3	20	80%
212	EB	34	F	4	30	80%
301	LB	40	F	17	23	60%
302	LB	38	F	22	16	50%
303	LB	28	F	14	14	60%
304	LB	23	F	15	8	40%
305	LB	27	F	19	8	70%
306	LB	25	F	15	10	50%
307	LB	41	F	26	14	50%
308	LB	44	F	14	30	25%
309	LB	39	F	15	24	70%
310	LB	23	M	14	9	20%
311	LB	34	F	19	15	50%
312	LB	39	F	16	23	50%

Appendix O: Language Background Questionnaire for Monolingual English Participants

Language Background Questionnaire for Monolingual English Participants

The aim of this questionnaire is to obtain information about you language history. Please complete this questionnaire to the best of your knowledge.

Participant (pseudonym): _____
Date: _____
Date of birth: _____ Gender: _____ Age: _____
Birthplace: _____ _____
Town/City State/Country
What is your highest level of education? _____
How did you find out about this study? _____
Occupation: _____

What is your 1st language_____ 2nd_____3rd_____
Were you born in the US? Please circle. YES NO
If "no", please inform researcher.

Years living in the US_____
Number of years of formal education in English-speaking country _____
Number of years of formal education in Spanish-speaking country _____

How many years of high school did you complete? _____
How many years of college did you complete? _____
How many years of graduate school did you complete? _____

Places You Have Lived (City/State/Country)	Years	Language Spoken

Parent 1's Birthplace: _____Languages Parent 1 spoke fluently: _____
Parent 1's Birthplace: _____Languages Parent 1 spoke fluently: _____

At what age did you first hear each of these languages regularly (please explain context):
English:
Spanish:
Other:

What languages were **spoken to you** when you were growing up? By whom? Please check.

	English	Spanish	Other language
Parents			
Siblings			
Grandparents			
Relatives			
Babysitter			
Friends			

What languages did **you speak** to the following people when you were growing up? Please check.

	English	Spanish	Other language
Parents			
Siblings			
Grandparents			
Relatives			
Babysitter			
Friends			

Do you have normal hearing? YES / NO
Have you had a recent hearing screening? YES___ NO____ If yes, what were the results?_____
Have you ever received speech-language therapy? YES_____ NO_____ If yes, when and for how many years? If yes, please describe (e.g., difficult producing sounds, trouble expressing ideas, etc...)_____
Were you in special education? YES _____ NO _____
Please add any comments/concerns _____

What do you consider your native language?
English Spanish
Other:_____

Please estimate how much you hear/speak **English** in these places/situations:

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Home											
School											
Work											
With friends											
Visiting family											
On the telephone											
At social events											
Listening TV/radio											

What other language(s) is/are spoken during the rest of the time? _____

Do you speak any language other than English on a regular basis? Please circle.
Strongly agree Somewhat agree Neutral Somewhat disagree strongly disagree

What percentage of English do you use on a regular basis? _____

What language do you prefer to use?_____

Please estimate your ability to speak, understand, read and write English and another language- use "1" to indicate "poor" skills and "7" to indicate "strong" skills.

	English								Other Language						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
Understanding															
Speaking															
Reading															
Writing															

Other Language: _____

Additional Comments (if any):

_____

_____

Thank You!

Appendix P: Language Background Questionnaire for Bilingual Participants

Language Background Questionnaire for Bilingual Participants

The aim of this questionnaire is to obtain information about you language history. Please complete this questionnaire to the best of your knowledge.

Participant (pseudonym): _____
Date: _____
Date of birth: _____ Gender: _____ Age: _____
Birthplace: _____ _____
Town/City State/Country
What is your highest level of education? _____
How did you find out about this study? _____
Occupation: _____

What is your 1st language_____ 2nd_____3rd_____
Age of arrival in the US_____
Years living in the US_____
Number of years of formal education in Spanish-speaking country _____
Number of years of formal education in English-speaking country _____

Places You Have Lived (City/State/Country)	Years	Language Spoken

Parent 1's Birthplace: _____Languages Parent 1 spoke fluently_____
Parent 2's Birthplace: _____Languages Parent 2 spoke fluently_____

At what age did you first hear each of these languages regularly (please explain context):
English:
Spanish:
Other:

How old were you when you started learning/acquiring English? _____
What languages were **spoken to you** when you were growing up? By who? Please check.

	English	Spanish	Other language
Parents			
Siblings			
Grandparents			
Relatives			
Babysitter			
Friends			

What languages did **you speak** to the following people when you were growing up? Please check.

	English	Spanish	Other language
Parents			
Siblings			
Grandparents			
Relatives			
Babysitter			
Friends			

School

If you attended elementary school in a Spanish speaking country, what language(s) were used in your classroom?

1. _____2. _____ 3._____ N/A

Before arriving to the US, how many years did you take English in:
elementary school (1st-8th grade)_____
high school:_____
college: _____
graduate school: _____
other:_____
n/a

If you attended elementary school in the US, what type of classroom were you in? Please circle.
English only Bilingual (Spanish-English) ESL n/a

If you attended high school in the US, what type of classroom were you in? Please circle.
English only Bilingual (Spanish-English) ESL n/a

How many years of high school did you complete? _____
How many years of college did you complete? _____
How many years of graduate school did you complete? _____

How many years in total did you study English? _____

Do you have normal hearing? YES / NO
Have you had a recent hearing screening? YES___ NO____ If yes, what were the results?_____
Have you ever received speech-language therapy? YES_____ NO_____ If yes, when and for how many years? If yes, please describe (e.g., difficult producing sounds, trouble expressing ideas, etc...)_____
Were you in special education? YES _____ NO _____
Please add any comments/concerns _____

What do you consider your native language?
English Spanish
Other:_____

Please estimate how much you hear/speak **Spanish** in these places/situations. Please write an "**H**" for hear and "**S**" for speak in the corresponding box.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Home											
School											
Work											
With friends											
Visiting family											
On the telephone											
At social events											
Listening TV/radio											

What other language(s) is/are spoken during the rest of the time? _____

Please estimate, using a percentage (%) how much you have spoken in Spanish in the past 5 years _____; in the past 5 months_____; in the past 5 weeks _____

Do you speak Spanish on a regular basis? Please circle.
Strongly agree Somewhat agree Neutral Somewhat disagree strongly disagree

What percentage of Spanish do you use on a regular basis? _____
What percentage of English do you use on a regular basis? _____

What language do you prefer to use?_____

Please estimate your ability to speak, understand, read and write English and Spanish- use "1" to indicate "poor" skills and "7" to indicate "strong" skills.

	English								Spanish						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
Understanding															
Speaking															
Reading															
Writing															

Additional Comments (if any):

Thank you!

Appendix Q.

Summary of mixed effects logistic regression for goodness rating scores on perceptual assimilation tasks in early and late bilingual listeners.

Scale	Coef.	Std. Err.	*z*	*p*	95% CI
Group	1.116	.567	1.97	*0.049	.004; 2.228
LB	4.786	.401	11.92	0.000	3.999; 5.572

Appendix R.

Summary of mixed effects logistic regression for perceptual assimilation patterns in EB (early bilingual) and LB (late bilingual) listeners

AE Vowel	Spanish Response Vowel	EB (%)	LB (%)	Odds Ratio	Std. Err.	Z	*p*	95% CI
/i/	/a/	0	0.2	—				
	/e/	4.1	3.3	1.286	0.978	0.33	.741	[0.29; 5.707]
	/i/	95.4	96.3	0.820	0.545	-0.3	.766	[0.223; 3.02]
	/o/	0.4	0	—				
	/u/	0.2	0.2	1.000	1.416	0	1	[0.062; 16.03]
/ɪ/	/a/	0.6	0.2	0.332	0.384	-0.95	.34	[0.034; 3.203]
	/e/	48.5	48.9	0.625	0.691	-0.42	.671	[0.072; 5.459]
	/i/	50	50	1.857	2.058	0.56	.577	[0.212; 16.301]
	/o/	0.2	0.9	5.019	6.443	1.26	.209	[0.405; 62.135]
	/u/	0.7	0	—				
/ɛ/	/a/	4.6	11.3	3.393	1.748	2.37	* .018	[1.236; 9.312]
	/e/	93.5	86.7	0.380	0.173	-2.12	* .034	[0.156; 0.929]
	/i/	0.7	0.6	0.749	0.574	-0.38	.706	[0.167; 3.361]
	/o/	0.2	1.5	8.167	9.076	1.89	.059	[0.925; 72.11]
	/u/	0.9	0	—				
/æ/	/a/	91.7	82	0.390	0.141	-2.6	*.009	[0.192; 0.794]
	/e/	7	13.5	2.197	0.888	1.95	*.051	[0.995; 4.851]
	/i/	0.2	0.6	2.989	3.864	0.85	.397	[0.237; 37.654]
	/o/	0.9	3.5	3.839	2.683	1.92	*.054	[0.976; 15.107]
	/u/	0.2	0.4	2.004	2.457	0.57	.571	[0.181; 22.163]
/ɑ/	/a/	82.6	75	0.679	0.482	-0.54	.586	[0.169; 2.733]
	/e/	0.4	1.3	4.407	5.537	1.18	.238	[0.375; 51.721]
	/i/	0	0.2	—				
	/o/	10.9	22.8	1.834	1.274	0.87	.383	[0.47; 7.156]
	/u/	6.1	0.7	0.174	0.223	-1.37	.172	[0.014; 2.141]
/ʌ/	/a/	29.4	53.1	9.729	9.122	2.43	*.015	[1.549; 61.119]
	/e/	4.3	6.7	1.675	1.171	0.74	.461	[0.426; 6.59]
	/i/	0.2	0.7	4.022	4.504	1.24	.214	[0.448; 36.105]
	/o/	24.4	38.5	2.545	1.837	1.29	.196	[0.618; 10.477]
	/u/	41.7	0.9	0.001	0.001	-3.66	*<.001	[0; 0.035]
/o/	/a/	0.9	0.3	0.332	0.384	-0.95	.34	[0.034; 3.2]
	/e/	0	1.5	—				
	/i/	0	0	—				
	/o/	96	97.8	0.972	1.304	-0.02	.983	[0.07; 13.485]
	/u/	3.1	0.3	0.415	1.190	-0.31	.759	[0.002; 114.374]

Appendix S.

Summary of mixed effects logistic regression for Discrimination Accuracy of AE Vowel Contrasts by Early (EB) and Late Bilingual (LB) Listeners

Fixed Effect	**Estimate(SE)**	***Z***	***P***	**95% CI**
/ɪ-i/	1.056(0.534)	1.98	*.048	[0.01, 2.103]
/æ-ɑ/	-0.541(0.359)	-1.51	.131	[-1.244, 0.162]
/ʌ-æ/	0.574(0.458)	1.25	.21	[-0.324, 1.473]
/ʌ-ɑ/	-0.082(0.39)	-0.21	.834	[-0.845, 0.682]
group-EB	-0.892(0.433)	-2.06	*.04	[-1.742, -0.043]
group-LB	-2.098(0.415)	-5.06	*<.001	[-2.911, -1.285]
/ɪ-i/×EB	-1.55(0.579)	-2.68	*.007	[-2.684, -0.415]
/ɪ-i/×LB	-1.28(0.559)	-2.29	*.022	[-2.374, -0.185]
/æ-ɑ/×EB	-0.898(0.414)	-2.17	*.03	[-1.71, -0.087]
/æ-ɑ/×LB	-0.344(0.391)	-0.88	.379	[-1.111, 0.423]
/ʌ-æ/ ×EB	-1.681(0.504)	-3.33	*.001	[-2.67, -0.692]
/ʌ-æ/ ×LB	-1.564(0.484)	-3.23	*.001	[-2.513, -0.615]
/ʌ-ɑ/ ×EB	-1.269(0.441)	-2.87	*.004	[-2.134, -0.403]
/ʌ-ɑ/ ×LB	-0.839(0.42)	-2	*.046	[-1.662, -0.016]
Intercept	3.395(0.353)	9.61	*<.001	[2.703, 4.088]
Random Effect				
Intercept	0.393(0.123)			[0.212, 0.727]

Appendix T.

Pairwise comparisons after Mixed effects logistic regression for Discrimination Accuracy of AE Vowel Contrasts by Monolingual (MO) Listeners and Early (EB) and Late Bilingual (LB) Listeners

Comparison	**Estimate(SE)**	***Z***	***P***	**95% CI**
Overall group effect				
EB vs MO	-1.985(0.318)	-6.24	*<.001	[-2.609, -1.361]
LB vs MO	-2.913(0.316)	-9.21	*<.001	[-3.533, -2.293]
LB vs EB	-0.928(0.269)	-3.45	*.001	[-1.455, -0.401]
Vowel Contrast /ɪ-i/				
EB vs MO	-2.442(0.549)	-4.45	*<.001	[-3.517, -1.367]
LB vs MO	-3.377(0.541)	-6.24	*<.001	[-4.438, -2.317]
LB vs EB	-0.936(0.315)	-2.97	*.003	[-1.553, -0.318]
Vowel Contrast /ɪ-ɛ/				
EB vs MO	-0.892(0.433)	-2.06	*.04	[-1.742, -0.043]
LB vs MO	-2.098(0.415)	-5.06	*<.001	[-2.911, -1.285]
LB vs EB	-1.205(0.334)	-3.61	*<.001	[-1.861, -0.55]
Vowel Contrast /æ-ɑ/				
EB vs MO	-1.791(0.369)	-4.86	*<.001	[-2.513, -1.068]
LB vs MO	-2.442(0.365)	-6.69	*<.001	[-3.157, -1.727]
LB vs EB	-0.651(0.298)	-2.19	*.029	[-1.235, -0.068]
Vowel Contrast /ʌ-æ/				
EB vs MO	-2.573(0.469)	-5.49	*<.001	[-3.492, -1.654]
LB vs MO	-3.661(0.464)	-7.89	*<.001	[-4.571, -2.752]
LB vs EB	-1.088(0.301)	-3.62	*<.001	[-1.678, -0.499]
Vowel Contrast /ʌ-ɑ/				
EB vs MO	-2.161(0.4)	-5.41	*<.001	[-2.944, -1.378]
LB vs MO	-2.937(0.396)	-7.42	*<.001	[-3.713, -2.161]
LB vs EB	-0.776(0.298)	-2.6	*.009	[-1.361, -0.191]

Appendix U.

Summary of mixed effects logistic regression for Identification Accuracy of AE Vowels by Early (EB) and Late Bilingual (LB) Listeners

Fixed Effect	**Estimate(SE)**	***Z***	***P***	**95% CI**
Vowel /ɪ/	0.536(0.297)	1.81	.071	[-0.046, 1.119]
Vowel /ɛ/	-0.075(0.259)	-0.29	.772	[-0.582, 0.432]
Vowel /æ/	0.458(0.289)	1.58	.113	[-0.109, 1.025]
Vowel /ɑ/	-1.815(0.216)	-8.39	*<.001	[-2.238, -1.391]
Vowel /ʌ/	-0.461(0.242)	-1.9	.057	[-0.936, 0.014]
Vowel /o/	0.159(0.315)	0.51	.613	[-0.459, 0.777]
group-EB	-0.628(0.471)	-1.33	.183	[-1.552, 0.296]
group-LB	-1.872(0.463)	-4.04	*<.001	[-2.78, -0.965]
Vowel /ɪ/ ×EB	-1.107(0.342)	-3.24	*.001	[-1.777, -0.436]
Vowel /ɪ/ ×LB	-1.785(0.326)	-5.48	*<.001	[-2.423, -1.147]
Vowel /ɛ/ ×EB	-0.392(0.31)	-1.26	.206	[-0.999, 0.215]
Vowel /ɛ/ ×LB	-0.485(0.291)	-1.67	.095	[-1.055, 0.085]
Vowel /æ/ ×EB	-1.502(0.333)	-4.51	*<.001	[-2.155, -0.849]
Vowel /æ/ ×LB	-1.291(0.318)	-4.06	*<.001	[-1.914, -0.668]
Vowel /ɑ/ ×EB	-0.94(0.277)	-3.4	*.001	[-1.482, -0.397]
Vowel /ɑ/ ×LB	-0.954(0.269)	-3.55	*<.001	[-1.482, -0.427]
Vowel /ʌ/ ×EB	-1.066(0.294)	-3.63	*<.001	[-1.641, -0.49]
Vowel /ʌ/ ×LB	-2.201(0.289)	-7.62	*<.001	[-2.767, -1.635]
Vowel /o/ ×EB	-0.925(0.368)	-2.51	*.012	[-1.647, -0.203]
Vowel /o/ ×LB	-0.917(0.35)	-2.62	*.009	[-1.603, -0.232]
Intercept	2.73(0.358)	7.63	*<.001	[2.029, 3.432]
Random Effects				
Intercept	0.921(0.234)			[0.56, 1.515]

Appendix V.

Pairwise comparisons after mixed effects logistic regression for Identification Accuracy of AE Vowels by Monolingual (MO) Listeners and Early (EB) and Late Bilingual (LB) Listeners

Comparison	**Estimate(SE)**	***Z***	***P***	**95% CI**
Overall group differences				
EB vs MO	-1.475(0.421)	-3.5	*<.001	[-2.301, -0.649]
LB vs MO	-2.978(0.42)	-7.08	*<.001	[-3.801, -2.154]
LB vs EB	-1.502(0.397)	-3.78	*<.001	[-2.281, -0.724]
Vowel /i/				
EB vs MO	-0.628(0.471)	-1.33	.183	[-1.552, 0.296]
LB vs MO	-1.872(0.463)	-4.04	*<.001	[-2.78, -0.965]
LB vs EB	-1.245(0.425)	-2.93	*.003	[-2.077, -0.412]
Vowel /ɪ/				
EB vs MO	-1.734(0.487)	-3.56	*<.001	[-2.69, -0.779]
LB vs MO	-3.657(0.481)	-7.6	*<.001	[-4.601, -2.714]
LB vs EB	-1.923(0.419)	-4.59	*<.001	[-2.744, -1.101]
Vowel /ɛ/				
EB vs MO	-1.019(0.465)	-2.19	*.028	[-1.931, -0.107]
LB vs MO	-2.357(0.458)	-5.14	*<.001	[-3.256, -1.459]
LB vs EB	-1.338(0.42)	-3.19	.001	[-2.16, -0.516]
Vowel /æ/				
EB vs MO	-2.13(0.481)	-4.43	*<.001	[-3.072, -1.188]
LB vs MO	-3.163(0.476)	-6.64	*<.001	[-4.096, -2.23]
LB vs EB	-1.033(0.416)	-2.48	*.013	[-1.85, -0.217]
Vowel /ɑ/				
EB vs MO	-1.567(0.438)	-3.58	*<.001	[-2.426, -0.709]
LB vs MO	-2.826(0.443)	-6.38	*<.001	[-3.695, -1.958]
LB vs EB	-1.259(0.425)	-2.96	*.003	[-2.093, -0.425]
Vowel /ʌ/				
EB vs MO	-1.693(0.453)	-3.74	*<.001	[-2.581, -0.805]
LB vs MO	-4.074(0.457)	-8.92	*<.001	[-4.969, -3.178]
LB vs EB	-2.38(0.424)	-5.61	*<.001	[-3.212, -1.549]
Vowel /o/				
EB vs MO	-1.553(0.506)	-3.07	*.002	[-2.544, -0.561]
LB vs MO	-2.79(0.498)	-5.6	*<.001	[-3.766, -1.814]
LB vs EB	-1.237(0.434)	-2.85	*.004	[-2.087, -0.387]

Appendix W.

Spearman correlation between discrimination accuracy and cross-language assimilation overlap by listener group

Group	Number of Observations	Spearman's rho	Probability > |t|
Early Bilingual	6	0.543	0.266
Late Bilingual	6	0.829	*0.042